U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-253 211

CASE STUDIES OF TRANSIT ENERGY AND AIR POLLUTION IMPACTS

De Leuw, Cather and Company, Incorporated

PREPARED FOR
Environmental Protection Agency

May 1976

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

PB253211

1. REPORT NO. EPA-600/5-76-003	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE CASE STUDIES OF TRANSIT ENERGY AND AIR POLLUTION IMPACTS		5. REPORT DATE May 1976 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) JAMES P. CURRY		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS De Leuw, Cather & Company 1201 Connecticut Avenue, N.W. Washington, D.C. 20036		10. PROGRAM ELEMENT NO. 1HA093 11. CONTRACT/GRANT NO. 68-01-2475
12. SPONSORING AGENCY NAME AND ADDRESS Office of Energy, Minerals and Industry Office of Research and Development U.S. Environmental Protection Agency Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED FINAL 14. SPONSORING AGENCY CODE EPA-ORD

15. SUPPLEMENTARY NOTES
Prepared in cooperation with TRW Environmental Services and Bigelow - Crain & Assoc.

16. ABSTRACT

The paper summarizes analysis of the energy consumption and air pollution impacts of eight case studies of new or improved transit services. The case studies include (a) areawide bus service improvement programs involving route extensions, increased frequencies, new lines, demand responsive service, and fare reductions; (b) new corridor exclusive busway service on the Shirley Highway and San Bernardino Freeway; and (c) new rail transit service in the Philadelphia-Lindenwold corridor. Probabilistic models were developed for each of these three service improvement scenerios to account for key travel demand and transportation system factors affecting energy consumption and air pollution impact levels. Results showed that low patronage response to areawide bus improvements as well as diversion from prior bus service, carpools, etc. and extensive auto access (park-and-ride, kiss-and-ride) to corridor systems reduce expected energy and air pollution gains and may, under certain conditions found in four case studies, result in possible energy use increases. Additionally, it was found that auto use for corridor system access may worsen air quality conditions in suburban areas in the vicinity of corridor transit terminal locations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Exhaust Emissions Mass Transportation Transportation Models	Energy Conservation	12B 21B

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 198
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE 7.50

155018

PB 253 211

EPA-600/5-76-003
May 1976

Socioeconomic Environmental Studies Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
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INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
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EPA-600/5-76-003
May 1976

CASE STUDIES OF TRANSIT ENERGY AND AIR POLLUTION IMPACTS

by

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OFFICE OF RESEARCH AND DEVELOPMENT
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FOREWORD

The continuing crisis in the supply of petroleum, the resulting call for strong measures to reduce fuel consumption in the transportation sector, and the potential effects such measures might have on the environment have caused the Office of Research and Development (ORD), U.S. Environmental Protection Agency to undertake studies of the effects that transportation-related energy conservation measures will have on petroleum demand and air quality.

This study examines the changes in fuel consumption and emission of air pollutants caused by the introduction of new transit services. A complementary study of the effects of policy measures aimed directly at the automobile (gasoline taxes, rationing, new car mileage regulations and excise taxes) is scheduled to be published at about the same time as this one.

The principal investigator of this study was Mr. James P. Curry of De Leuw, Cather & Company, 1201 Connecticut Avenue, N.W., Washington, D.C. Mr. Edgar A. Gonzalez of De Leuw, Cather was responsible for model development and analyses as well as case studies data collection. Mr. William E. Piske of TRW Environmental Services assisted with study methodology development and directed air quality inputs preparation. Mr. Charles Scardino, also of TRW Environmental Sciences, was responsible for air quality inputs and assisted with case studies data collection. Mr. John L. Crain of Bigelow-Crain Associates provided data regarding the San Bernardino busway and Orange County projects, in addition to providing key study review inputs. Ms. Christine L. Nelson of De Leuw, Cather prepared all report illustrations. The EPA project officer for the study was Mr. Steven E. Plotkin of the Office of Energy, Minerals and Industry.

A major conclusion of this report reflects what thoughtful proponents of mass transit expansion have always known...that expansion of service without extremely careful attention to latent demand, system competitiveness with alternate transportation modes, and selection of appropriate equipment, schedules and operating methods can lead to a less rather than more efficient transportation system. The *theoretical* edge in efficiency and environmental attractiveness of mass transit over the automobile is enormous; the actual edge is, *on the average*, much less but still significant. In a particular case, the advantage may evaporate, as shown in this report. We conclude by this that, as much as general support for mass transit is admirable from an environmental standpoint, we must judge each case by its merits... certainly not a unique idea.

Stephen J. Gage
Deputy Assistant Administrator
for Energy, Minerals and Industry
U.S. Environmental Protection Agency

ABSTRACT

This report summarizes an analysis of the energy consumption and air pollution impacts of eight case studies of new or improved transit services. The case studies include (a) areawide bus service improvement programs involving route extensions, increased frequencies, new lines, demand responsive service, and fare reductions; (b) new corridor exclusive busway service on the Shirley Highway and San Bernardino Freeway; and (c) new rail transit service in the Philadelphia-Lindenwold corridor. Probabilistic models were developed for each of these three service improvement scenarios to account for key travel demand and transportation system factors affecting energy consumption and air pollution impact levels. Results showed that low patronage response to areawide bus improvements as well as diversion from prior bus service, carpools, etc. and extensive auto access (park-and-ride, kiss-and-ride) to corridor systems reduce expected energy and air pollution gains and may, under certain conditions found in four case studies, result in possible energy use increases. Additionally, it was found that auto use for corridor system access may worsen air quality conditions in suburban areas in the vicinity of corridor transit terminal locations.

TABLE OF CONTENTS

Chapter Page

1. STUDY SUMMARY AND MAJOR FINDINGS 1
    1.1 Introduction 1
    1.2 Selection of Case Studies 4
    1.3 Methodology 5
    1.4 Study Findings 12
        1.4.1 Finding No. 1 12
        1.4.2 Finding No. 2 19
        1.4.3 Finding No. 3 25
    1.5 Further Research 29

2. STUDY METHODOLOGY 31
    2.1 Introduction 31
        2.1.1 Selection of Case Studies 32
        2.1.2 Model Development 33
    2.2 Key Factors Affecting Energy Consumption and Air Pollution Impacts 38
        2.2.1 Auto and Transit Unit Air Pollutant Emissions Characteristics 39
            2.2.1.1 Diverted Auto Cold Starts 40
            2.2.1.2 Diverted Auto Driving Cycles 43
            2.2.1.3 Bus Air Pollutant Emissions 43
            2.2.1.4 Rail Transit Air Pollutant Emissions 46
        2.2.2 Auto and Transit Unit Energy Consumption Characteristics 46
            2.2.2.1 Improved Auto Efficiency 49
            2.2.2.2 Bus Energy Consumption Characteristics 50
            2.2.2.3 Rail Transit Energy Consumption 53
        2.2.3 Ridership Response to New Transit Services 60

TABLE OF CONTENTS (Continued)

Chapter Page

2.2.3.1 Short-Term Changes in Travel Behavior. . . 61
2.2.3.2 Long-Term Changes in Travel Behavior . . . 63

3. EXPANDED REGIONAL BUS SERVICE
3.1 Introduction 66
3.1.1 Methodology 69
3.2 Atlanta. 72
3.2.1 New Ridership 73
3.2.2 Diversion of Automobile Trips 74
3.2.3 Net Energy Consumption Savings. 74
3.2.4 Net Air Pollutant Emissions Reduction 78
3.3 Washington 78
3.3.1 Net Energy Consumption Savings. 80
3.3.2 Net Air Pollutant Emissions Reduction 85
3.4 San Diego. 89
3.4.1 New Ridership 91
3.4.2 Net Energy Consumption Savings. 92
3.4.3 Net Air Pollutant Emissions Reduction 96
3.5 Orange County. 104
3.5.1 New Ridership 105
3.5.2 Net Energy Consumption Savings. 105
3.5.3 Net Air Pollutant Emissions Reduction 105

4. NEW CORRIDOR EXPRESS BUS SERVICE 110
4.1 Introduction 110
4.1.1 Methodology 111
4.2 Shirley Highway Busway 112
4.2.1 Diversion from Auto Driving 115
4.2.2 Busway Access Mode. 117
4.2.3 Busway Influence on Residence Location. 117

TABLE OF CONTENTS (Continued)

Chapter Page

4.2.4 Busway Passenger Load Factors. 120
4.2.5 Net Energy Consumption Savings 120
4.2.6 Net Air Pollutant Emissions Reduction. 122
4.3 San Bernardino Busway 125
4.3.1 Diversion from Auto Driving. 127
4.3.2 Busway Access Mode 129
4.3.3 Use of Auto Left at Home 129
4.3.4 Busway Influence on Residence Location Choice. . . 131
4.3.5 Net Energy Consumption Savings 133
4.3.6 Net Air Pollutant Emission Reduction 139

5. NEW CORRIDOR RAIL TRANSIT SERVICE. 143
5.1 Introduction. 143
5.1.1 Methodology. 144
5.2 Bay Area Rapid Transit. 144
5.2.1 Corridor Mode Choice and Diversion to BART 146
5.2.2 Previous Travel Mode 148
5.2.3 Mode of BART Access. 148
5.3 Lindenwold Rapid Transit. 151
5.3.1 Corridor Mode Choice and Diversion to Lindenwold Line 153
5.3.2 Mode of Access to Lindenwold Line. 153
5.3.3 Access and Line Haul Trip Lengths. 153
5.3.4 Net Energy Consumption Savings 156
5.3.5 Net Air Pollutant Emissions Reduction. 156
5.4 Rail Transit Air Pollutant Emissions 160
APPENDIX A. Methodology Description and Input Data. 163
APPENDIX B. Selected References 182

LIST OF FIGURES

Number		Page
1.1	Generalized Busway Model	11
1.2	Fuel Consumption Reduction, Washington, D. C.	14
1.3	Reduction in Fuel Consumption, San Diego Action Plan	15
1.4	Reduction in Fuel Consumption, Orange County, California	17
1.5	Reduction in Fuel Consumption, San Diego Fare Reduction	18
1.6	Reduction in Fuel Consumption, Lindenwold High Speed Line	20
1.7	Lindenwold High Speed Line Before and After Peak Period Energy Consumption	21
1.8	Shirley Busway Before and After Energy Consumption	23
1.9	San Bernardino Busway Before and After Energy Consumption	24
1.10	San Bernardino Busway, Distribution of CO Changes	26
2.1	CO Emission Rates Versus Auto Trip Length	42
2.2	Auto Gasoline Consumption (Versus Trip Length)	48
2.3	Bus Fuel Consumption and Average Route Speed	51
2.4	Bus Fuel Consumption and Bus Stop Frequency	52
3.1	Trend of Average Fare	67
3.2	Trend of Vehicle Miles	67
3.3	Trend of New Motor Buses	67
3.4	Trend of Revenue Passengers	68
3.5	Fuel Consumption Reduction, Atlanta, Georgia	77
3.6	CO Emissions Reduction, Atlanta, Georgia	79
3.7	Fuel Consumption Reduction, Washington, D. C.	81
3.8	Effect of Auto Diversion Rate in Fuel Consumption Reduction, Washington, D. C.	82
3.9	Break-even Values, Washington, D. C.	83
3.10	Effect of Auto Diversion Rate in Fuel Consumption Reduction, Washington, D. C. (Improved auto fuel consumption)	84

LIST OF FIGURES (Continued)

Number Page

3.11 Reduction in CO Emissions. Washington, D.C.. 86
3.12 Effect of Auto Diversion Rate in Reduction of CO Emissions Washington, D.C.. 87
3.13 Air Quality Index Readings. Washington, D.C. July, 1974. . . 90
3.14 Reduction in Fuel Consumption. San Diego Fare Reduction. . . 93
3.15 Reduction in Fuel Consumption. San Diego Fare Reduction. . . 94
3.16 Reduction in Fuel Consumption. San Diego Fare Reduction. . . (Improved auto fuel consumption). 95
3.17 Reduction in Fuel Consumption. San Diego Action Plan. . . . 97
3.18 Reduction in Fuel Consumption. San Diego Action Plan 98
3.19 Reduction in Fuel Consumption. San Diego Action Plan, (Improved auto fuel consumption 99
3.20 Reduction in CO Emissions. San Diego Fare Reduction. 100
3.21 Reduction in CO Emissions. San Diego Fare Reduction. 101
3.22 Reduction in CO Emissions. San Diego Action Plan 102
3.23 Reduction in CO Emissions. San Diego Action Plan 103
3.24 Reduction in Fuel Consumption. Orange County, California, (25 percent auto trip diversion). 106
3.25 Reduction in Fuel Consumption, Orange County, California, (50 percent auto trip diversion). 107
3.26 Reduction in Fuel Consumption, Orange County, California. . . 108
3.27 Reduction in CO Emissions. Orange County California. 109

4.1 Generalized Busway Model. 114
4.2 Shirley Highway Busway. Washington 116
4.3 Shirley Busway Daily Fuel Savings 121
4.4 Shirley Busway Before and After Energy Consumption. 123
4.5 Shirley Busway Daily CO Emissions Reduction 124
4.6 San Bernardino Busway. Los Angeles 126
4.7 San Bernardino Busway Daily Fuel Savings. 134
4.8 San Bernardino Busway. Before and After Energy Consumption . 135
4.9 Approximate Volume - Speed Relationship 137
4.10 Auto Fuel Consumption 138
4.11 San Bernardino Busway Daily CO Emissions Reduction. 140
4.12 San Bernardino Busway. Distribution of CO Changes 142

LIST OF FIGURES (Continued)

Number Page

5.1 Reduction in Fuel Consumption. Lindenwold High Speed Line. . 157

5.2 Reduction in Fuel Consumption, Lindenwold 158

5.3 Lindenwold High Speed Line. Before and After Peak Period Energy Consumption. 159

5.4 Reduction in CO Emissions. Lindenwold High Speed Line. . . . 161

A.1 Typical Beta Distribution 165

A.2 CO Emissions Reduction. Atlanta, Ga. 174

LIST OF TABLES

Number Page

1.1 Typical Energy Consumption and Air Pollutant Emission Rates . 6
1.2 Selected Data on Corridor Transit Case Studies. 7
1.3 Factors Affecting Energy Consumption and Air Pollutant Emission Changes Due to Expanded Regional Bus Service 8
1.4 Factors Affecting Energy Consumption and Air Pollutant Emission Changes for New Corridor Transit Service 9

2.1 Factors Affecting Energy Consumption and Air Pollutant Emission Changes Due to Expanded Regional Bus Service 35
2.2 Factors Affecting Energy Consumption and Air Pollutant Emission Changes for New Express Busway Service 36
2.3 Factors Affecting Energy Consumption and Air Pollutant Emission Changes for New Rail Transit Service 37
2.4 Comparison of Driving Cycle and Federal test Procedure. CO Emission Factors. 44
2.5 Average 1975 CO Emission Factors with Driving Cycle Correction. 45
2.6 Bus Air Pollutant Emission Factors. 47
2.7 Comparison of Estimated Energy Use Components 55
2.8 Total Automobile Energy Use, 1971 59
2.9 Driver Trips in Multi-Car Households. 65

3.1 Selected Operating Data for Case Studies. 70
3.2 Factors Affecting Energy Consumption and Air Pollutant and Emission Changes Due to Expanded Regional Bus Service 71
3.3 Previous Travel Mode for Atlanta New Bus Riders 75
3.4 Weekday Distribution of Previous Automobile Drivers 76
3.5 Summary of 1975 Transportation Control Strategy for Washington Metropolitan Region 88

4.1 Factors Affecting Energy Consumption and Air Pollutant Emission Changes for New Express Busway Service 113

LIST OF TABLES (Continued)

Number		Page
4.2	Previous Travel Mode of Shirley Busway Riders, AM Peak Period	118
4.3	Mode of Access for Shirley Busway Riders, AM Peak Period. . .	119
4.4	Previous Travel Mode of San Bernardino Busway Users	128
4.5	Mode of Access for San Bernardino Busway Users.	130
4.6	Use of Commuting Car Left at Home	132
5.1	Factors Affecting Energy Consumption and Air Pollutant Emission Changes for New Rail Transit Service	145
5.2	San Francisco East Bay Mode Split AM Peak Period.	147
5.3	San Francisco East Bay Mode Split All Day, Both Directions. .	149
5.4	Previous Travel Mode of BART Passengers, 1973	150
5.5	Mode of BART Access, 1973	152
5.6	Previous Travel Mode of Lindenwold Passengers, 1970	154
5.7	Estimated Mode of Access for Lindenwold Line Users, 1970. . .	155
5.8	Estimated 1975 Contribution of Rail Transit Operations to Annual Regional Air Pollutant Emissions	162
A.1	Values Used in AREAWIDE Computer Model. Atlanta, Ga.	169
A.2	Values Used in AREAWIDE Computer Model. Washington, D.C. . .	170
A.3	Values Used in AREAWIDE Computer Model. San Diego Fare Reduction	171
A.4	Values Used in AREAWIDE Computer Model. San Diego Action Plan.	172
A.5	Values Used in AREAWIDE Computer Model. Orange County. . . .	173
A.6	Values Used in AREAWIDE Computer Model. San Diego Fare Reduction Trip Length Parametric Analysis	175
A.7	Values Used in AREAWIDE Computer Model. San Diego Action Plan. Trip Length Parametic Analysis	176
A.8	Values Used in BUSWAY Computer Model. Shirley Busway	179
A.9	Values Used in BUSWAY Computer Model. San Bernardino Busway.	180
A.10	Values Used in CORAIL Computer Model. Lindenwold Rapid Rail.	181

CHAPTER 1

STUDY SUMMARY AND MAJOR FINDINGS

1.1 INTRODUCTION

Current policy considerations regarding energy conservation and production independence, as well as requirements of the 1970 Clean Air Act regarding attainment of ambient air quality standards have both pointed to the development of improved public transportation services as a key program element. Such expansions of transit service hold the promise of reductions in both air pollutant emissions and transportation energy consumption. Comparison of typical auto and transit air pollution and energy consumption characteristics indicates the relative attractiveness of transit[1]. On a seat-miles basis, transit is two to four times more energy efficient than the automobile and many times less polluting.

The actual effectiveness of new public transportation services in providing major pollution reduction and energy savings without the introduction of major auto-use restraint or crisis conditions is for the most part not well established[2]. Much of the reported research has dealt with variations in the energy use and air pollutant emissions characteristics of alternative transportation systems under assumed or empirically 'average' conditions.

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[1] For example--Healy, T. J. Energy Use of Public Transit Systems. Prepared for the California Department of Transportation, August 1974. Lansing, N. F. and H. R. Ross. Energy Consumption by Transit Mode. Prepared for the Southern California Association of Governments, March 1974. The MITRE Corporation. Transportation Energy and Environmental Issues. February, 1972.

[2] TRW/De Leuw, Cather & Company. Travel Impacts of Fuel Shortage and Price Increase Conditions. Prepared for the U. S. Environmental Protection Agency, December 1974.

It is the general finding of this study that the use of average conditions without full attention to the actual characteristics of new transit trips has distorted analysis of transit energy and air pollution impacts. Under many conditions found in case studies carried out in this project, new or improved transit services may have distinctly negative energy and air pollution impacts. More specifically, the following factors may be significant determinants of transit energy consumption and air pollutant emissions impacts:

- new transit ridership diverted from carpooling or other transit service, from trips made in small autos, and being trips not previously taken;
- the number and length of trips made by auto to access new corridor transit service;
- the length of former auto trips made on new transit services--are long or short auto trips being diverted to transit;
- 'cold start' air pollutant emissions effects associated with corridor transit access trips made by auto;
- the effects of improved auto traffic flow due to trips diverted to new transit service;
- effects of current trend towards smaller autos with improved energy efficiency;
- use of a former commuting auto for other trips by other household members; and
- indirect energy consumption for transit or highway system construction and operation.

Despite transit's apparent attractiveness for energy conservation and air quality, study results indicate that transit's limited ability to capture new riders, especially former automobile users, and the continued use of autos for corridor transit system access following its development without effective collection-distribution service can substantially reduce (and in some cases eliminate) expected energy use or overall air pollution savings. Futhermore, current trends towards lighter automobiles with greater fuel efficiency serve to reduce transit's fuel saving potential since diverted auto trip energy is lowered. A comprehensive approach to transit development to maximize its energy and air pollution reduction effectiveness is required if full advantages are to be realized.

This report describes results of a research study undertaken for the Environmental Protection Agency in which the net energy consumption and air pollutant emissions[1] changes associated with eight case studies of new or improved transit services have been examined. The case studies are representative of three new transit service scenarios:

- Bus service improvements on a region-wide basis consisting of route extensions, increased operating frequencies, new lines, reduced fare programs, and demand-responsive service;
- Corridor express bus service via exclusive bus lanes; and
- Corridor commuter rail transit service utilizing modern rail transit equipment and performance standards.

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[1] Only limited analysis was carried out for pollutants other than carbon monoxide and hydrocarbons.

The case studies involving recent examples of the introduction of new or improved service for each scenario were chosen to provide a data base regarding changes in trip-making behavior following transit service changes.

It should be cautioned that case study results have been developed using available data for key factors which, in many instances, has been incomplete or limited. Parametric analyses and techniques for recognizing the degree of uncertainty associated with study variables were invoked to accommodate incomplete data. Furthermore, study results do not have long-range applicability particularly with regard to potential transit impacts on land use and urban development patterns, which may have direct and substantial impacts on regional energy use and air quality.

1.2 SELECTION OF CASE STUDIES

Eight case studies were selected to provide inputs for study analyses. They were chosen on the basis of data availability and to provide as wide a range as possible of new or improved transit service examples. Case studies span a spectrum of service levels, characterized by modal shares from a few percent of total regional or corridor travel to nearly one-half of all trips during peak periods.

Five case studies involved expanded regional bus service:

	Fare Reduction	Improved Headways and Route Extensions	Demand Actuated Service
Atlanta (1972)	X	X	
Washington (1974-75)		X	

	Fare Reduction	Improved Headways and Route Extensions	Demand Actuated Service
San Diego (1973)	X	X	
San Diego (1975-)		X	
Orange County, California (1974-75)			X

Selected data describing before and after conditions for each of the five cases are summarized in Table 1.1.

Two case studies involved new corridor busway--one operating on the Shirley Highway in suburban Washington, D. C. and the second via the San Bernardino Freeway in the Los Angeles area. Finally, the Lindenwold high-speed commuter rail line was reviewed as a corridor rail transit case study. Preliminary Bay Area Rapid Transit (BART) data was also compiled for comparison but no energy or air pollution analysis was carried out. Selected data for each of the three corridor transit case studies is presented in Table 1.2.

1.3 METHODOLOGY

Each of the case studies was analyzed using simple models which incorporated all factors affecting energy consumption and air pollution impacts for which reasonable data could be found and applied. Table 1.3 summarizes relevant factors for expanded regional bus service, and the availability of data items for each of the case studies. Data for most key factors was not generally available, and was inferred from what was available or from secondary sources for analysis purposes. In Table 1.4, relevant factors for new corridor transit service studies are listed with available data

TABLE 1.1

SELECTED OPERATING DATA FOR CASE STUDIES

Case Study	Approximate Population (millions)	BEFORE Daily Bus miles (thousands)	BEFORE Daily Ridership (thousands)	BEFORE Base Fare (cents)	AFTER Daily Bus miles (thousands)	AFTER Daily Ridership (thousands)	AFTER Base Fare (cents)
Atlanta (1972)	1.6	64	185	40	75	237	15
Washington (1973-74)	3.0	159	433	40	185	456	40
San Diego (1972)	1.4	27	51	40	35	82	25
San Diego (1974-)	1.4	35	82	40	58	104	25
Orange County (1974)	1.5	-	-	-	21	24	25-50

TABLE 1.2

SELECTED DATA ON CORRIDOR TRANSIT CASE STUDIES

	Shirley Busway	San Bernardino Busway	Lindenwold Rapid Rail
Major Metropolitan Service Areas	Washington, D.C.	Los Angeles	Philadelphia
Year Opened	1969	1973	1969
Corridor Length (miles)	11.0	11.0	12.5
Ridership (Peak Hours Only)	23,000	9,500	8,000 (1)
Diverted Autos (Peak Hours)	9,200	7,300	2,670 (1)
System Access			
Park and Ride	5,500	5,200	4,700
Dropped Off	2,000	1,600	1,600

(1) Morning Peak Only.

Table 1.3

FACTORS AFFECTING ENERGY CONSUMPTION AND AIR POLLUTANT EMISSION CHANGES DUE TO EXPANDED REGIONAL BUS SERVICE

		DATA AVAILABILITY					
		ATLANTA	WASHINGTON	SAN DIEGO	SAN DIEGO	ORANGE COUNTY	OTHER
LEVEL OF BUS SERVICE	NEW BUS-MILES OF SERVICE	●	●	●	●	●	
	FARE CHANGE	●		●			
BUS RIDERSHIP	NEW RIDERSHIP	●	●	●	●	●	
	LOAD FACTOR	●	●	●	●	●	●
	PREVIOUS TRAVEL MODE INCLUDING DIVERSION FROM CARPOOLS	●					
AUTO TRIP DIVERSION	NUMBER OF AUTOS DIVERTED	●					
	DIVERTED AUTO TRIP LENGTH						●
	TIME OF DAY OF DIVERTED AUTO TRIPS	●					
	REGIONAL LOCATION OF DIVERTED AUTO TRIPS		●				
	DIVERTED AUTO UNIT GASOLINE CONSUMPTION						●
	DIVERTED AUTO UNIT EMISSIONS						●
	BUS UNIT FUEL CONSUMPTION						●
	BUS UNIT EMISSIONS						●
OUTPUT	NET 1975 CO EMISSIONS REDUCTION						
	NET 1975 HC EMISSIONS REDUCTION						
	NET 19/5 FUEL SAVINGS						
	NET FUEL SAVINGS WITH IMPROVED AUTOS						

Table 1.4

FACTORS AFFECTING ENERGY CONSUMPTION AND AIR POLLUTANT EMISSION CHANGES FOR NEW CORRIDOR TRANSIT SERVICE

		DATA AVAILABILITY				
		SHIRLEY BUSWAY	SAN BERNARDINO BUSWAY	BART	LINDENWOLD HIGH-SPEED LINE	OTHER
TRANSIT RIDERSHIP	NEW RIDERSHIP	●	●		●	
	PEAK PERIOD LOAD FACTOR	●				
	OFF-PEAK LOAD FACTOR	●				
	PREVIOUS TRAVEL MODE INCLUDING DIVERSION FROM CARPOOLS	●	●	●	●	
CORRIDOR SERVICE DESCRIPTION	LENGTH OF LINE	●	●		●	
	CORRIDOR TRIBUTARY AREA	●	●		●	
	STATION SPACING	●	●	●	●	●
	RAIL TRANSIT UNIT ENERGY CONSUMPTION					●
	RAIL TRANSIT UNIT EMISSIONS					
AUTO DIVERSION	NUMBER OF AUTOS DIVERTED	●	●	●	●	
	DIVERTED AUTO TRIP LENGTH				●	
	TIME OF DAY OF DIVERTED AUTOS	●	●	●		
	REGIONAL LOCATION OF DIVERTED AUTO TRIPS	●	●		●	
	DIVERTED AUTO UNIT GASOLINE CONSUMPTION					●
	DIVERTED AUTO UNIT EMISSIONS					●
FORMER BUS RIDERS	NUMBER OF TRIPS DIVERTED FROM FORMER BUS SERVICE	●	●	●	●	
	FORMER BUS SERVICE LOAD FACTOR	●		●		
	BUS UNIT FUEL CONSUMPTION					●
	BUS UNIT EMISSIONS					●
ACCESS MODE	NUMBER OF PARK-AND-RIDE PASSENGERS	●	●	●	●	
	NUMBER OF KISS-AND-RIDE PASSENGERS	●	●	●	●	
	NUMBER OF FEEDER BUS PASSENGERS	●	●	●	●	
	UNIT FUEL CONSUMPTION FOR AUTO ACCESS TRIPS					●
	UNIT EMISSIONS FOR AUTO ACCESS TRIPS					●
	FEEDER BUS UNIT FUEL CONSUMPTION					●
	FEEDER BUS UNIT EMISSIONS					●
	ACCESS TRIP LENGTH				●	
LONG-TERM IMPACTS	RESIDENCE LOCATION CHANGE	●	●			
	REDUCED AUTO OWNERSHIP					
	REDUCED TRAFFIC CONGESTION			●	●	
	OTHER USE OF AUTO		●			
OUTPUT	NET 1975 CO EMISSIONS REDUCTION					
	NET 1975 HC EMISSIONS REDUCTION					
	NET 1975 FUEL SAVINGS					
	NET FUEL SAVINGS WITH IMPROVED AUTOS					

summaries noted. Again, data for several key factors was missing and was approximated for study analysis.

A key aspect of the modeling procedures was the capability to handle important factors as random variables with associated probability functions. In this manner, the known variations of certain factors due to local conditions or operating procedures as well as the uncertainty involved in specifying values for other factors where there is little or conflicting available information was accommodated, and in turn, directly reflected in estimates of output planning variables[1]. For example, unit fuel consumption rates and pollutant emission rates were treated as random input variables from probability distribution functions defined by lower bound, modal, and upper bound values which accounted for the range of empirical and other published data. Similarly, data regarding the former trip characteristics of new transit service riders, which may have a substantial impact on energy consumption results, was incompletely reported. For study analysis purposes, available data was used to define appropriate probability distribution functions for application to case studies where specific data items were not reported.

For the bus and rail transit corridor models, simplified corridor configuration and operating policy assumptions were required. As shown in Figure 1.1, the model assumed a user-defined rectangular corridor configuration with (a) busway passenger demand uniformly distributed within the specified service area which means that approximately the same number of buses enter the busway at each entry point, and (b) buses assumed to circulate through a portion of the service area for passenger collection before entering

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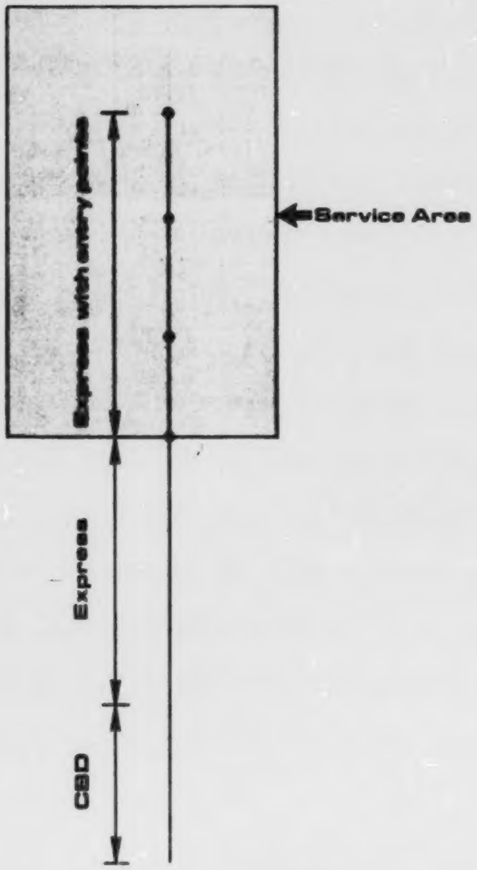
[1] Pei, R. Y. and I. F. Kan. "A Decision Aid to Transportation Planners." Paper presented at 41st Annual Meeting of the Operations Research Society of America, New Orleans.

1.1

GENERALIZED BUSWAY MODEL


Express with entry points
Service Area
Express
CBD

the busway. Average bus load factors were taken from Shirley busway reported experience, and individual route frequencies determined by applying the average load factor at each busway entry point. Neighborhood bus routes were assumed to provide complete one-quarter mile coverage over a rectangular grid street network in the defined service area. Similar assumptions were invoked for the corridor rail transit model.

1.4 STUDY FINDINGS

Detailed analysis of travel demand and transportation system characteristics of eight new transit service case studies has demonstrated three principal findings with general application for transit planning and implementation.

- New ridership response to areawide bus service improvement programs including route extensions, improved service frequencies, and new bus lines, and demand responsive service may reduce system load factors resulting in net energy use increases;
- Energy consumption savings for corridor transit service improvements are significantly reduced due to diversion to new transit service from other transit and carpooling, auto use for corridor system access, and corridor transit system energy requirements;
- Air quality in suburban areas may be worsened by auto trip making involving cold starts for corridor transit system access.

1.4.1 FINDING NO. 1

New ridership response to areawide bus service improvement programs including route extensions, improved service frequencies, new bus lines, and demand-actuated service may reduce average system load factors resulting in net energy use increases.

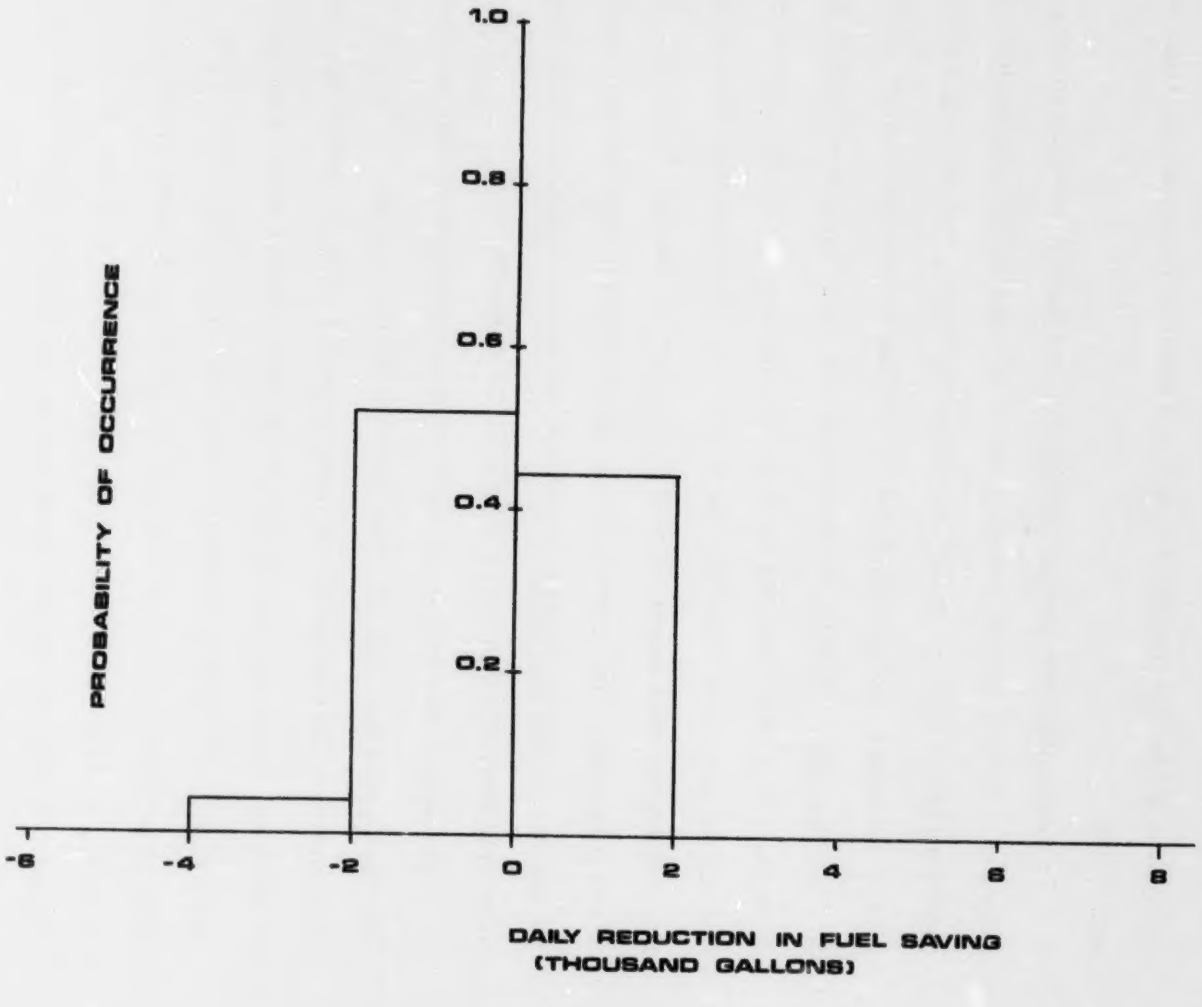
For case studies involving increased bus-miles of service in San Diego, Washington, and Orange County, greater energy consumption was estimated to result from the introduction of expanded service due to the low patronage response and the low proportion of new transit users diverted from prior auto trips.

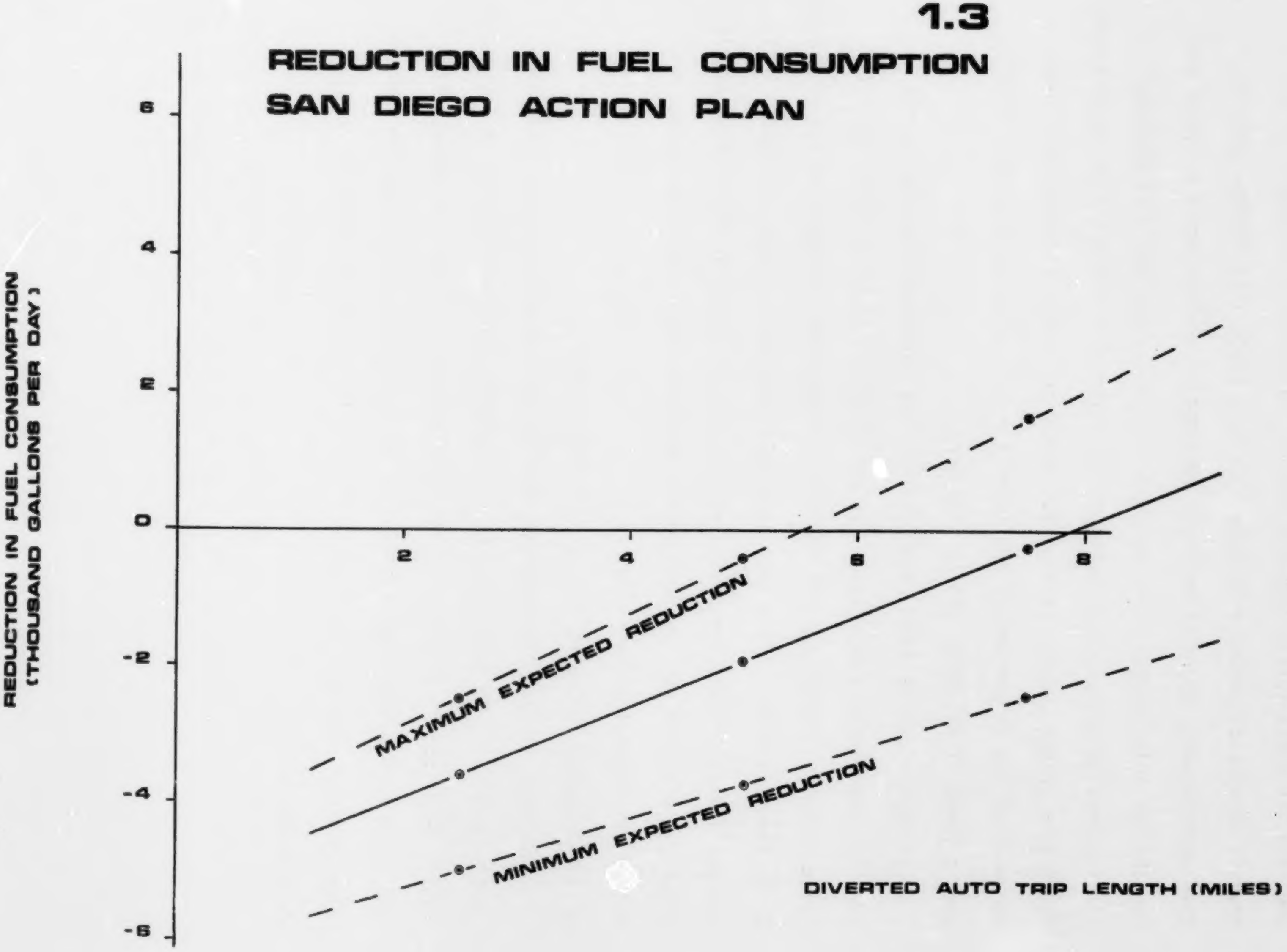
In developing the energy consumption estimates, incomplete data regarding diverted auto trip characteristics was available as already noted. Data regarding prior mode of travel collected following the Atlanta fare reduction program was used as input for all areawide bus improvement case studies. In Atlanta, approximately 42 percent of new bus riders were former auto drivers, i.e., less than one-half of the new bus trips represented elimination of an auto trip from Atlanta's streets. Furthermore, Atlanta survey data indicated that approximately 21 percent of new bus trips were trips not previously made. New transit trips not previously made do not contribute to any reductions in energy use or air pollution levels although they reflect increased mobility for certain population segments.

The output net energy consumption probability distribution function for the Washington bus service improvement program is shown in Figure 1.2, demonstrating approximately 56 percent probability of energy use increase conditions. This was one of the three case studies which generated increased energy use. Parametric studies of net energy savings over a range of diverted auto trip characteristics--percent of new transit users diverted from auto driving, diverted auto trip length--were conducted to support study findings. Figure 1.3 illustrates estimated energy consumption savings resulting from

1.2

FUEL CONSUMPTION REDUCTION
WASHINGTON, D.C.





1.3

REDUCTION IN FUEL CONSUMPTION
SAN DIEGO ACTION PLAN

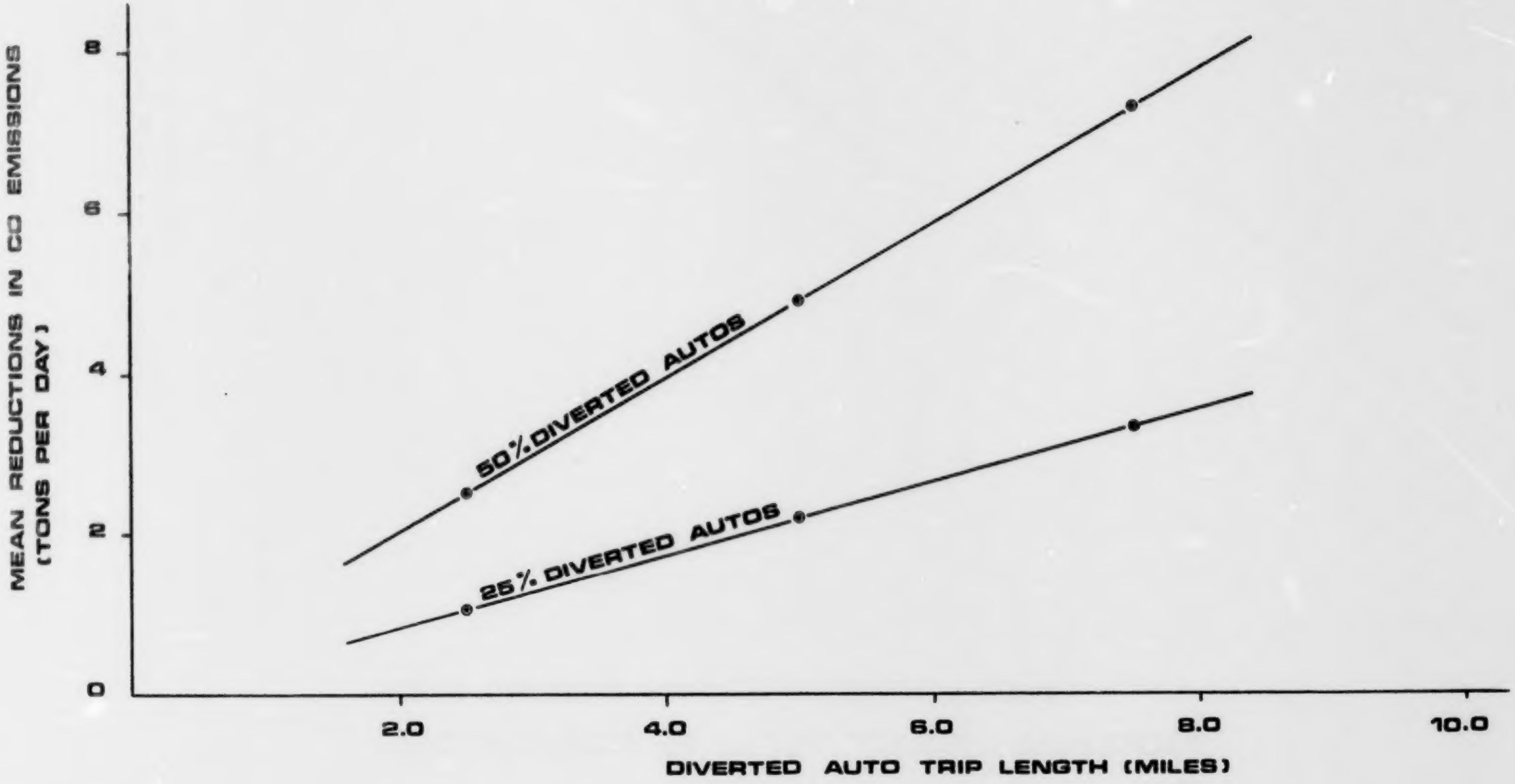
the 1975 San Diego Action Plan bus service improvements program. If new transit service attracted auto trips having average trip lengths greater than approximately eight miles, fuel consumption savings would be generated. For shorter trip lengths, increased overall fuel usage would be expected. Similar results are plotted in Figure 1.4 for the introduction of "dial-a-ride" service in Orange County, showing estimated net energy consumption changes for both 25 and 50 percent of new transit riders diverted from auto driving over a range of diverted auto trip lengths.

In each of these three case studies, low ridership response to new services represents a key reason for negative energy consumption results. For example, a sixteen percent increase in bus miles operated in the Washington, D. C. area generated only a four percent ridership increase. Assuming that the new transit riders are traveling the same distance on the average as old riders; the system average load factor has decreased. In fact, unless new riders are traveling four times as far or longer, the system load factor will be reduced following the service improvements.

Two case studies involved bus service improvement programs including fare reductions. In both instances, ridership response resulted in increased system load factors and significant fuel savings. Figure 1.5 demonstrates the range of expected fuel savings for the San Diego fare reduction program, showing actual savings for diverted auto trip lengths as short as approximately two miles.

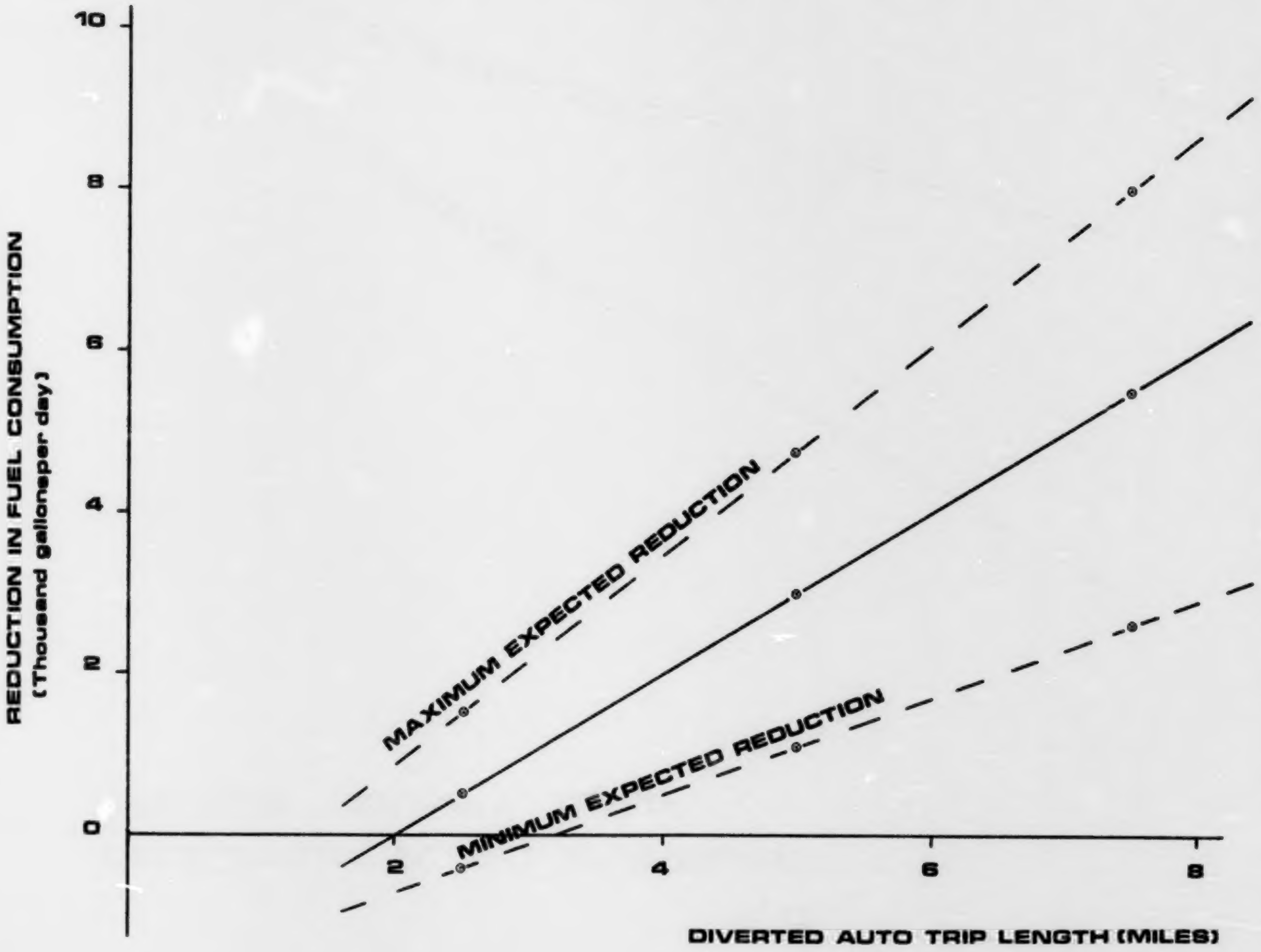
1.4

REDUCTION IN CO EMISSIONS ORANGE COUNTY, CALIF.



1.5

REDUCTION IN FUEL CONSUMPTION SAN DIEGO FARE REDUCTION



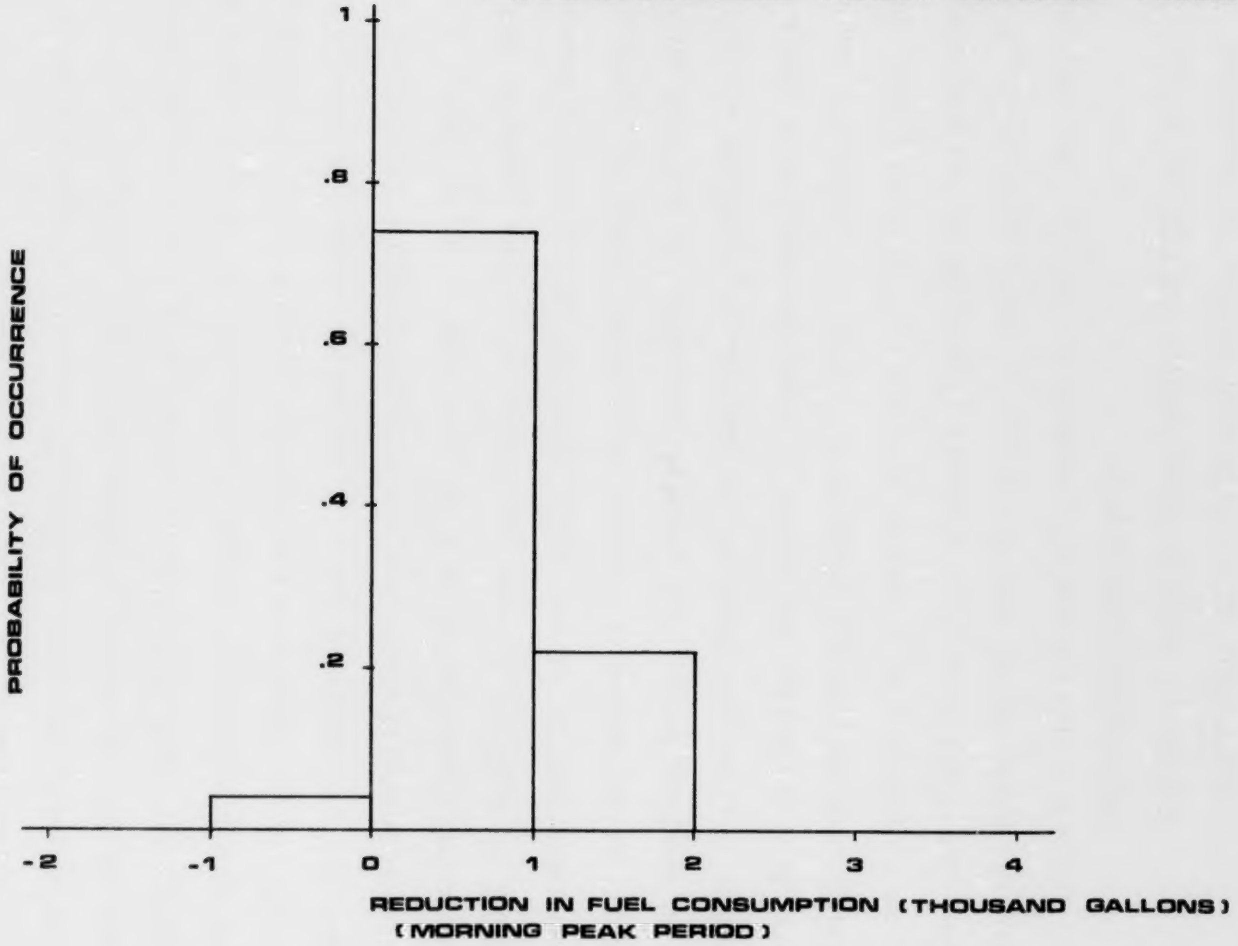
1.4.2 FINDING NO. 2

Energy consumption savings for corridor transit service improvements are significantly reduced due to diversion to new transit service from other transit and carpooling, auto use for corridor system access, and corridor transit system energy requirements.

Analysis of the Lindenwold high-speed rail transit line indicated only small net energy savings with probability of actual increased energy consumption. The output probability distribution function derived from model analysis of the Lindenwold line is plotted in Figure 1.6. Lindenwold rider survey results revealed that only twenty-eight percent of Lindenwold riders were diverted from corridor auto driving in comparison with approximately 40 percent shifting from former bus and commuter rail passenger service. Furthermore, nearly 90 percent of Lindenwold users reach the system by auto, either by driving and parking at a station or by being dropped off. Both factors have contributed to the net energy impact results. Figure 1.7 summarizes before and after energy consumption components in the Lindenwold corridor, reflecting actual corridor trip characteristics. 'Before' energy consumption includes estimated former auto and transit consumption for corridor trips now using the Lindenwold line. 'After' energy consumption includes estimated energy use for system access by auto, for Lindenwold rail transit propulsion and vehicle accessories, and for limited feeder bus service, resulting in an overall net energy savings equivalent to 800 gallons of refined gasoline per peak period. This amount is substantially lower than would be expected from examination of individual modal energy efficiencies under average load factor conditions as have been frequently reported.

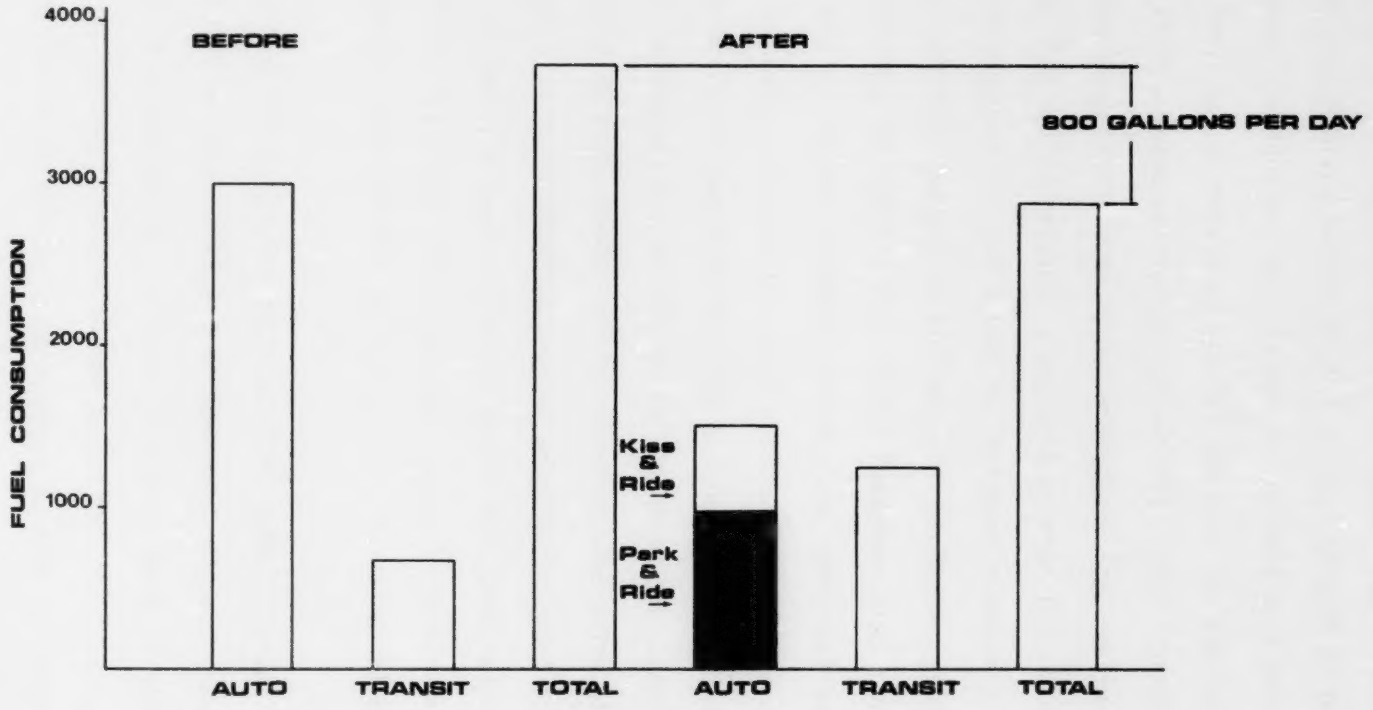
1.6

REDUCTION IN FUEL CONSUMPTION
LINDENWOLD HIGH SPEED LINE



1.7

LINDENWOLD HIGH SPEED LINE BEFORE AND AFTER PEAK PERIOD ENERGY CONSUMPTION

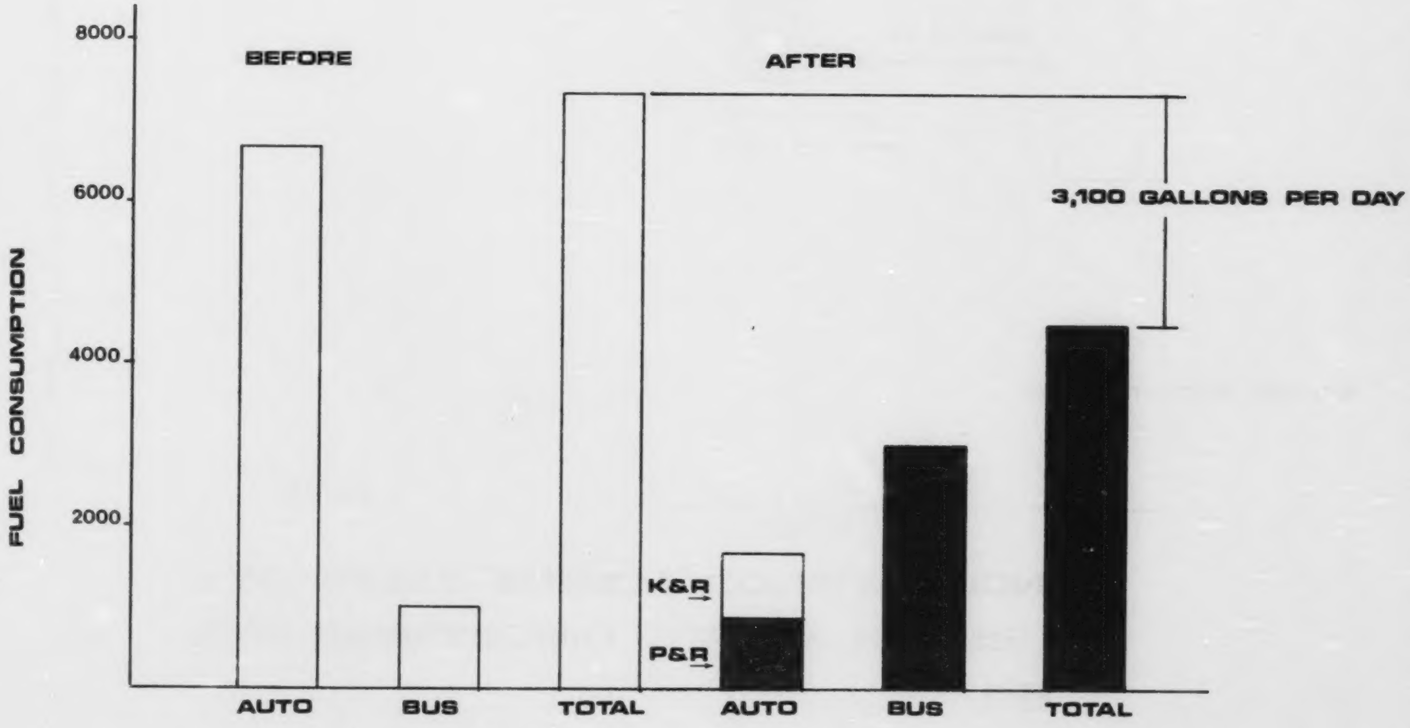


For the Shirley Highway and San Bernardino busway case studies, significant energy consumption savings have been generated, although as summarized in Figures 1.8 and 1.9, potential savings have been reduced through diversion from previous bus service and carpooling, increased bus fuel consumption, and auto use for busway system as was found for the Lindenwold rail transit line. For the San Bernardino busway, nearly 80 percent of new corridor bus riders were former auto driver commuters since there was little transit service previously operated in the corridor. This has provided tremendous leverage for generating net energy consumption and air pollution reductions. In the Shirley Highway corridor, only 40 percent of the new riders represent former auto drivers and approximately one-third have shifted from other bus service, somewhat similar to trip characteristics found in the Lindenwold corridor. System auto access levels also vary between the San Bernardino and Shirley busways reflecting different operating practices. Approximately 72 percent of San Bernardino riders reach the system by auto while two-thirds of Shirley busway users walk to catch corridor service buses circulating in neighborhoods prior to entering the busway. In the latter case, the energy use of circulating buses is a significant factor. No comparisons of energy consumption for different levels of auto and walk access (with bus circulation through service area neighborhoods) were conducted.

Figure 1.8 also includes estimated after energy consumption by autos no longer used for commuting in the San Bernardino corridor but left at home and used by other household members. Survey responses from San Bernardino busway users indicated that approximately 25 percent of autos formerly used for commuting were no longer used on a regular basis, genrating opportunities

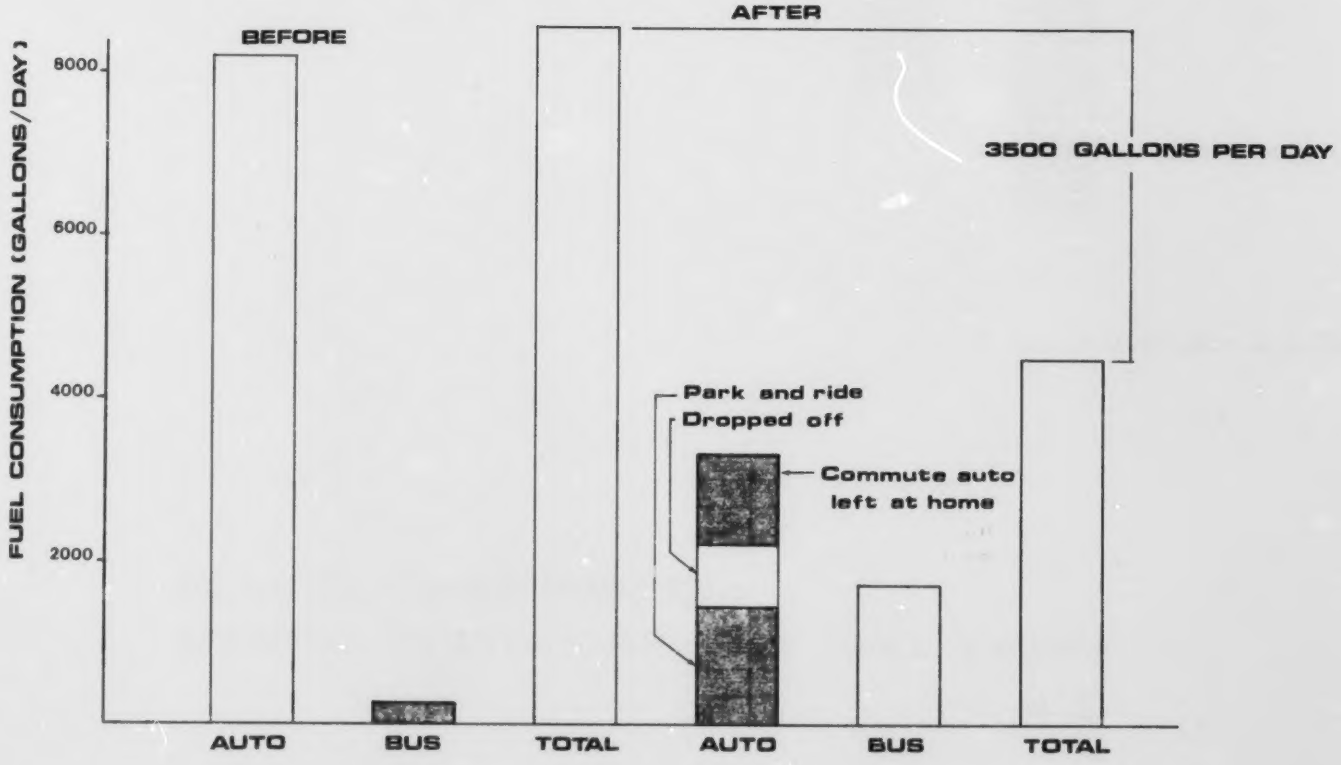
1.8

SHIRLEY BUSWAY BEFORE AND AFTER ENERGY CONSUMPTION



1.9

SAN BERNARDINO BUSWAY BEFORE AND AFTER ENERGY CONSUMPTION



for reducing household auto ownership. Of the remainder, about 15 percent were reported being utilized for trips by other household members and approximately 60 percent were used for trips to and from busway terminal locations. Both latter uses of autos formerly used for commuting might permit replacement of the commuting autos for ones in poor repair or deferment of needed repairs or replacement, generating potential economic benefits in either instance for new busway users.

Analysis of the San Bernardino corridor traffic diversion characteristics indicated a potential secondary impact due to reduced traffic congestion approximately equal to the energy savings generated by diversion to transit use due to reduced corridor traffic congestion. No data was available to validate this second-order impact for the San Bernardino corridor although available traffic volume data for both the Lindenwold and BART corridors showed that similar traffic impacts did not materialize as expected.

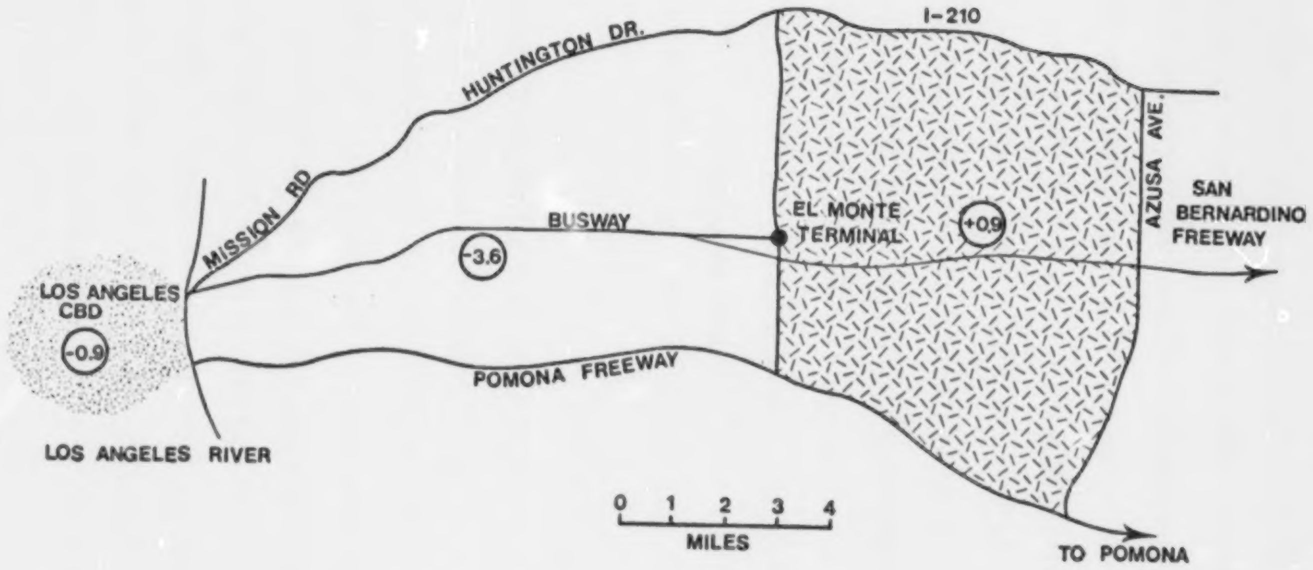
1.4.3 FINDING No. 3

Air Quality in suburban areas may be worsened by auto trip making involving cold starts for system access.

Figure 1.10 illustrates the distribution of carbon monoxide (CO) emissions changes in the San Bernardino Freeway corridor due to busway service introduction, showing a significant increase in CO emissions occuring in the vicinity of the El Monte terminal. Regional air pollution levels are often as high or higher in suburban areas as in central portions of the region, and the localized impact noted for the San Bernardino corridor should not be minimized because of its suburban location.

1.10

SAN BERNARDINO BUSWAY DISTRIBUTION OF CO CHANGES


HUNTINGTON DR.
I-210
MISSION RD
BUSWAY
-3.6
EL MONTE TERMINAL
+0.9
AZUSA AVE.
SAN BERNARDINO FREEWAY
LOS ANGELES CBD
-0.9
POMONA FREEWAY
LOS ANGELES RIVER
0
1
2
3
4
MILES
TO POMONA

For the reported study, automobile air pollutant emission rates were estimated to account for the specific characteristics of auto trips diverted to transit. For example, a corridor busway would divert auto trips having a driving cycle composed of suburban, corridor, and urban segments which may be quite different than the cycle assumed for the Federal Test Procedures (FTP) upon which the Environmental Protection Agency emissions estimation procedures is based. Also, pollution effects associated with cold vehicle starts have greater significance when considering trips diverted to transit and recent research findings regarding cold start emissions are applicable.

A cold start may be defined as the starting of a vehicle after it has been inoperative for some period of time such that the engine is below operational temperatures. The combination of inefficient combustion, due to the engine being below its operational temperatures, and the rich fuel to air ratio caused by the choke leads to excess carbon monoxide (CO) and hydrocarbon (HC) emissions. The Federal Test Procedure for motor vehicle emissions testing requires that a vehicle be left standing for a period of at least twelve hours before it is tested as a cold start vehicle. The difference between emissions generated in approximately four minutes after starting under these conditions and emissions for warmed-up running conditions are designated as being due to a cold start. Recent research[1] indicates that the standard procedure may be overly strict, and that a cold start probably occurs after only six or eight hours of non-use at normal ambient temperature ranges.

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[1] Argonne National Laboratory. Handbook of Air Pollutant Emissions from Transportation Systems. Prepared for Illinois Institute of Environmental Quality, December, 1973.

Recent studies[1] using travel data for the Washington and Pittsburgh metropolitan areas assumed that cold starts may be associated with all trips that originated at home or work. Applying this criterion which reflects recent cold start research findings, it was estimated that approximately 60 percent of all daily trips involve a cold start whereas the FTP assumes that cold starts are associated with only 43 percent of urban area trips. On this basis, cold start emissions related to trip volumes but not to trip lengths or speeds amount to approximately one-quarter of total carbon monoxide (CO) emissions and about 15 percent of total hydrocarbon (HC) emissions.

These results have particular significance when considering transit trip characteristics. First, it is expected that a high proportion of auto trips diverted to new transit service would include elimination of cold start emissions. To illustrate this rationale, 1972 survey data for Washington, D. C. bus trips showed that 69 percent of daily trips were for work purposes. Assuming that all work trips and that about 40 percent of the remainder involve cold starts, an estimated 81 percent of all bus trips if made by auto would involve cold starts. Similar data for other metropolitan areas show that between 70 and 90 percent of all diverted auto trips would have cold starts. Consequently, transit trips may represent a potentially higher payoff for air quality improvement due to elimination of work trips involving cold starts at both the home and work trips ends. Second, use of an automobile for transit system access trips may lessen potential reductions in CO and HC emissions emitted in the vicinity of the point of transit system access. San Bernardino case study results demonstrated that this does occur and may serve to worsen air quality conditions in suburban areas although overall corridor improvements are obtained.

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[1] Horowitz, J. L. and L. M. Pernela. "Comparison of Automobile Emissions According to Trip Type in Two Metropolitan Areas." Presented at 54th Annual Meeting of the Transportation Research Board, January 1975.

1.5 FURTHER RESEARCH

In carrying out the reported analysis, only limited data regarding a number of factors which have considerable influence on energy consumption and air quality results was found. For example, data regarding prior mode of travel of new transit riders was only available for one case study of areawide bus service improvements (i.e., Atlanta). For other case studies, the Atlanta data was employed to define a probability distribution function and additional parametric analysis was also carried out to bound analysis results. As a second example, trip length data was only reported for the Lindenwold Line and partially for the Shirley Busway case studies and estimates based on corridor/area characteristics were used for other case studies, again to define input probability distributions. Both these data items are key determinants of energy and air pollution impacts but only limited data was found for analysis purposes. In conclusion, additional research studies are required for several areas of importance for complete assessment of energy and air pollution impacts of new transit service projects:

- identification of the characteristics of new transit riders especially prior mode of travel and trip length;
- ridership response to short-range transit improvement programs involving route extensions, new lines, public information, improved headways, and demand responsive service;

- corridor system access mode choice characteristics and determinants;
- household auto ownership and trip generation impacts following new transit service introduction specifically with regard to latent trip demand, auto ownership reduction, and use of former commute autos for other trips;
- corridor traffic congestion impacts following new transit service introduction offering substantial energy and air quality improvement potential;
- second-order residence location and other land use impacts of new corridor transit service; and
- comparison of transit and highway system indirect energy utilization for construction and operations.

CHAPTER 2

STUDY METHODOLOGY

2.1 INTRODUCTION

The methodology employed for carrying out study analyses considered factors affecting the potential energy consumption savings and air pollutant emissions reduction of new or improved transit services of two general types:

- energy consumption and air pollutant emissions characteristics of transit vehicles and automobiles under varying operating conditions; and

- changes in both short- and long-term travel behavior in response to the increased level of transit service.

Three new transit service scenerios were selected for analysis:

- bus service improvements on a region-wide basis consisting of route extensions, increased operating frequencies, new lines, reduced fare programs, and demand-actuated service;

- corridor express bus service via exclusive bus lanes; and

- corridor commuter rail transit service utilizing modern rail transit equipment and performance standards.

Case studies involving recent examples of the introduction of new or improved service for each scenario were chosen to provide a data base regarding changes in trip-making behavior following transit service changes.

2.1.1 SELECTION OF CASE STUDIES

A total of nine case studies were selected to provide inputs for study analyses. They were chosen on the basis of data availability, and to provide as wide a range as possible of new or improved transit service examples. Case studies span a wide spectrum of service levels, characterized by model shares from a few percent of total regional or corridor travel to nearly one-half of all trips during perk periods.

Five case studies involved expanded regional bus service of three types:

	Fare Reduction	Improved Headways and Route Extensions	Demand Actuated Service
Atlanta (1972)	X	X	
Washington (1974-75)		X	
San Diego (1973)			
San Diego (1975-)		X	
Orange County, California (1974-75)			X

Two case studies involved new corridor busway -- one operating on the Shirley Highway in suburban Washington, D. C. and the second via the San Bernardino Freeway in the Los Angeles area. Finally, the Lindenwold high-speed commuter rail line and the Bay Area Rapid Transit (BART) were reviewed as corridor rail transit case studies, although no detailed analysis was carried out for BART due to the lack of available data for full system operations.

Case study data will generally not address more than directly-measured model shift changes following new transit service introduction, although considerable research has been reported describing impacts of the Lindenwold rail transit service introduction, and major research effort is currently being applied to measure BART systems impacts. In the course of this project, it has been important to recognize (1) inconsistencies among case studies in view of data limitations; and (2) means of handling inconsistencies which may include:

- ignoring them;
- inferring estimates from available information; or
- carrying out parametric analyses to bound potential impact levels.

The shortcomings of a case study approach have been documented on previous occasions.[1] However, they remain the principal means of learning about travel behavior characteristics and interrelationships with transportation system attributes and land development patterns. At the 1972 Williamsburg Conference on Urban Travel Demand Forecasting, one of the key recommendations was to extend efforts in analyzing "before" and "after" data for transportation system changes.[2]

2.1.2 MODEL DEVELOPMENT

Three general computer models -- one each for studying (a) regional bus service improvements, (b) new express corridor busway service, and (c) new corridor rail transit service -- were developed and applied to analyze the case studies of improved transit service.

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[1] Charles River Associates, Inc. Measurement of the Effects of Transportation Changes. Prepared for the Urban Mass Transportation Administration. August, 1972. Boyce, D. C. "Notes on the Methodology of Urban Transportation Impact Analysis" in Impact of the BART System on the San Francisco Metropolitan Region, Highway Research Board Special Report III. 1972.

[2] Brand, D. and M. L. Manheim, eds. Urban Travel Demand Forecasting, Transportation Research Board Special Report, 143. 1973.

As summarized in Tables 2.1, 2.2, and 2.3, the models were designed to accommodate key factors affecting energy consumption and air quality impacts in one or more of six ways:

- as a fixed input value.
- as an input random variable -- in this case, lower bound, modal, and upper bound values must be specified. Then, values for the variable are sampled from an approximate beta distribution function defined according to lower bound, modal, and upper bound inputs.[1]
- as an output random variable -- by repeatedly sampling values for input random variables, probability functions for output variables (which are a function of input variables) may be derived.
- parametrically where a range of fixed input values are specified to study output changes.
- according to default relationships -- the capability to generate a probability function for selected variables expected as input, but not available, on the basis of other input data items was incorporated. For example, diverted auto trip length was generated as a function of urban area population size in studying regional bus service improvements.[2]

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[1] Pei, R. Y. and I. F. Kan. "A Decision Aid to Transportation Planners." Paper presented at 41st Annual Meeting of the Operations Research Society of America, New Orleans.

[2] Alan M. Voorhees & Associates. "Factors and Trends in Trip Lengths," National Cooperative Highway Research Program Report No. 48. 1968.

TABLE 2.1

FACTORS AFFECTING ENERGY CONSUMPTION AND AIR POLLUTANT EMISSION CHANGES DUE TO EXPANDED REGIONAL BUS SERVICE

		DATA AVAILABLE						MODEL ANALYSIS				
		ATLANTA	WASHINGTON	SAN DIEGO	SAN DIEGO	ORANGE COUNTY	OTHER	INPUT	RANDOM VARIABLE	PARAMETRIC ANALYSIS	OUTPUT	BREAKEVEN
LEVEL OF BUS SERVICE	NEW BUS-MILES OF SERVICE	●	●	●	●	●		●				
	FARE CHANGE	●		●				●				
BUS RIDERSHIP	NEW RIDERSHIP	●	●	●	●	●		●				
	LOAD FACTOR	●	●	●	●	●	●					
	PREVIOUS TRAVEL MODE INCLUDING DIVERSION FROM CARPOOLS	●										
AUTO TRIP DIVERSION	NUMBER OF AUTOS DIVERTED	●							●	●		●
	DIVERTED AUTO TRIP LENGTH						●		●	●		●
	TIME OF DAY OF DIVERTED AUTO TRIPS	●										
	REGIONAL LOCATION OF DIVERTED AUTO TRIPS		●									
	DIVERTED AUTO UNIT GASOLINE CONSUMPTION						●		●	●		●
	DIVERTED AUTO UNIT EMISSIONS						●		●	●		●
	BUS UNIT FUEL CONSUMPTION						●		●	●		●
	BUS UNIT EMISSIONS						●		●			
OUTPUT	NET 1975 CO EMISSIONS REDUCTION										●	
	NET 1975 HC EMISSIONS REDUCTION										●	
	NET 1975 FUEL SAVINGS										●	
	NET FUEL SAVINGS WITH IMPROVED AUTOS										●	

TABLE 2.2

FACTORS AFFECTING ENERGY CONSUMPTION AND AIR POLLUTANT EMISSION CHANGES FOR NEW EXPRESS BUSWAY SERVICE

		DATA AVAILABLE			MODEL ANALYSIS			
		SHIRLEY BUSWAY	SAN BERNARDINO BUSWAY	OTHER	INPUT	RANDOM VARIABLE	PARAMETRIC ANALYSIS	OUTPUT
BUS RIDERSHIP	NEW RIDERSHIP	●	●		●			
	PEAK PERIOD	●				●		
	OFF-PEAK LOAD FACTOR	●						
	PREVIOUS TRAVEL MODE INCLUDING DIVERSION FROM CARPOOLS	●	●					
CORRIDOR SERVICE DESCRIPTION	LENGTH OF BUSWAY	●	●		●			
	CORRIDOR TRIBUTARY AREA	●	●		●			
	ENTRY/EXIT SPACING	●	●		●			
	BUS UNIT FUEL CONSUMPTION			●		●		
	BUS UNIT CO EMISSIONS			●		●		
AUTO DIVERSION	NUMBER OF AUTOS DIVERTED	●	●		●	●		
	DIVERTED AUTO TRIP LENGTH					●		
	TIME OF DAY OF DIVERTED AUTOS	●	●					
	REGIONAL LOCATION OF DIVERTED AUTO TRIPS	●	●					
	DIVERTED AUTO UNIT GASOLINE CONSUMPTION			●		●	●	
	DIVERTED AUTO UNIT EMISSIONS			●		●	●	
FORMER BUS RIDERS	NUMBER OF TRIPS DIVERTED FROM FORMER BUS SERVICE	●	●		●	●		
	FORMER BUS SERVICE LOAD FACTOR	●		●		●		
	BUS UNIT FUEL CONSUMPTION			●		●		
	BUS UNIT EMISSIONS			●		●		
ACCESS MODE	NUMBER OF PARK-AND-RIDE PASSENGERS	●	●		●	●		
	NUMBER OF KISS-AND-RIDE PASSENGERS	●	●		●	●		
	NUMBER OF FEEDER BUS PASSENGERS	●	●		●	●		
	UNIT FUEL CONSUMPTION FOR AUTO ACCESS TRIPS			●		●	●	
	UNIT EMISSIONS FOR AUTO ACCESS TRIPS			●		●	●	
	FEEDER BUS UNIT FUEL CONSUMPTION			●		●		
	FEEDER BUS UNIT EMISSIONS			●		●		
LONG TERM IMPACTS	RESIDENCE LOCATION CHANGE	●	●					
	REDUCED AUTO OWNERSHIP							
	REDUCED TRAFFIC CONGESTION							
	OTHER USE OF AUTO		●					
OUTPUT	NET 1975 HC EMISSIONS REDUCTION							●
	NET 1975 FUEL SAVINGS							●
	NET FUEL SAVINGS WITH IMPROVED AUTOS							●
	NET 1975 CO EMISSIONS REDUCTION							●

TABLE 2.3

FACTORS AFFECTING ENERGY CONSUMPTION AND AIR POLLUTANT EMISSION CHANGES FOR NEW RAIL TRANSIT SERVICE

		DATA AVAILABLE			MODEL ANALYSIS			
		BART	LINDENWOLD	OTHER	INPUT	RANDOM VARIABLE	PARAMETRIC ANALYSIS	OUTPUT
TRANSIT RIDERSHIP	NEW RIDERSHIP		●		●			
	PEAK PERIOD LOAD FACTOR					●		
	OFF-PEAK LOAD FACTOR							
	PREVIOUS TRAVEL MODE INCLUDING DIVERSION FROM CARPOOLS	●	●					
CORRIDOR SERVICE DESCRIPTION	LENGTH OF LINE		●		●			
	CORRIDOR TRIBUTARY AREA		●		●			
	STATION SPACING		●		●			
	RAIL TRANSIT UNIT ENERGY CONSUMPTION	●	●			●		
	RAIL TRANSIT UNIT EMISSIONS			●				
AUTO DIVERSION	NUMBER OF AUTOS DIVERTED	●	●		●	●		
	DIVERTED AUTO TRIP LENGTH		●		●			
	TIME OF DAY OF DIVERTED AUTOS	●						
	REGIONAL LOCATION OF DIVERTED AUTO TRIPS		●					
	DIVERTED AUTO UNIT GASOLINE CONSUMPTION			●		●	●	
	DIVERTED AUTO UNIT EMISSIONS			●		●	●	
FORMER BUS RIDERS	NUMBER OF TRIPS DIVERTED FROM FORMER BUS SERVICE	●	●		●	●		
	FORMER BUS SERVICE LOAD FACTOR	●		●		●		
	BUS UNIT FUEL CONSUMPTION			●		●		
	BUS UNIT EMISSIONS			●		●		
ACCESS MODE	NUMBER OF PARK-AND-RIDE PASSENGERS	●	●		●	●		
	NUMBER OF KISS-AND-RIDE PASSENGERS	●	●		●	●		
	NUMBER OF FEEDER BUS PASSENGERS	●	●		●	●		
	UNIT FUEL CONSUMPTION FOR AUTO ACCESS TRIPS			●		●	●	
	UNIT EMISSIONS FOR AUTO ACCESS TRIPS			●		●	●	
	FEEDER BUS UNIT FUEL CONSUMPTION			●		●		
	FEEDER BUS UNIT EMISSIONS			●		●		
	ACCESS TRIP LENGTH		●		●	●		
LONG-TERM IMPACTS	RESIDENCE LOCATION CHANGE							
	REDUCED AUTO OWNERSHIP							
	REDUCED TRAFFIC CONGESTION	●	●					
	OTHER USE OF AUTO							
OUTPUT	NET 1975 CO EMISSIONS REDUCTION							●
	NET 1975 HC EMISSIONS REDUCTION							●
	NET 1975 FUEL SAVINGS							●
	NET FUEL SAVINGS WITH IMPROVED AUTOS							●

- output values to "break-even" with regard to net energy consumption or air pollutant emissions.

A key aspect of the modeling procedures was the capacity to handle factors as random variables with associated probability functions. In this manner, the known variations of certain factors due to local conditions or operating procedures as well as the uncertainty involved in specifying values for other factors where there is little or conflicting available information may be accommodated, and in turn, directly reflecting in estimates of output planning variables. Input variables were characterized by an approximate beta probability distribution function permitting specification of a lower bound, modal, and upper bound value for the variable (instead of mean and estimated variance, for example).[1] The models as developed are generally applicable for regional or corridor sketch planning purposes, and this capability to handle variables as ranges or according to default conditions is a powerful asset for generating first approximation results in a quick manner. The results of this approach are fully displayed in subsequent chapters.

The remainder of this chapter presents an overview of factors incorporated in the study methodology. Additional information primarily relating to changes in travel characteristics due to new or improved transit service introduction for each of the case studies follows in Chapters 3-5.

2.2 KEY FACTORS AFFECTING ENERGY CONSUMPTION AND AIR POLLUTION IMPACTS

Case studies data and project analyses were directed towards identification and assessment of factors affecting net energy consumption savings and air pollutant emissions changes associated with the introduction of new or improved transit services including:

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[1] Hertz, D. B. "The Risk Analysis in Capital Investment" in Harvard Business Review, Volume 42, January-February, 1964.

- auto and transit unit air pollutant emissions characteristics;
- auto and transit unit energy consumption characteristics;
- ridership response to new transit services including system load factor levels;
- previous mode of travel of new transit service users;
- use of auto for transit system access; and
- second-order impacts not directly considered in this study including the use of autos formerly employed for commuting for other household trips, and possible reductions in auto traffic congestion due to diversion to transit.

2.2.1 AUTO AND TRANSIT UNIT AIR POLLUTANT EMISSIONS CHARACTERISTICS

Automobile emission rates for CO and HC were estimated to account for specific characteristics of auto trips diverted to transit. For example, a corridor busway would divert auto trips having a driving cycle composed of suburban, corridor, and urban segments which may be quite different than the cycle assumed for the Federal Test Procedures (FTP) upon which the Environmental Protection Agency emissions estimation procedure is based.[1] More specifically, unit auto emissions factors were developed with special attention to two refinements:

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[1] United States Environmental Protection Agency. Compilation of Air Pollutant Emission Factors. Second Edition, AP-42, September, 1973.

- application of recent research findings regarding cold start emissions; and

- use of more representative driving cycles instead of the FTP.

2.2.1.1 Diverted Auto Cold Starts

A cold start may be defined as the starting of a vehicle after it has been inoperative for some period of time such that the engine is below operational temperatures. The combination of inefficient combustion, due to the engine being below its operational temperatures, and the rich fuel to air ratio caused by the choke leads to excess carbon monoxide (CO) and hydrocarbon (HC) emissions.

The Federal Test Procedure for motor vehicle emissions testing requires that a vehicle be left standing for a period of at least twelve hours before it is tested as a cold start vehicle. The difference between emissions generated in approximately four minutes after starting under these conditions and emissions for warmed-up running conditions are designated as being due to a cold start. Recent research by the Angonne National Laboratory[1] indicates that the standard procedure may be overly strict, and that a cold start probably occurs after only six or eight hours of non-use at normal ambient temperature ranges.

Recent studies by Horowitz and Pernela[2] using travel data for the Washington and Pittsburgh metropolitan areas assumed that cold starts may be associated with all trips that originated at home or work. Applying this criterion which reflects recent cold start research findings, it was estimated that approximately 60 percent of all daily trips involve a cold start whereas the FTP assumes that cold starts are associated with only 43 percent of urban area trips. On this basis, cold start emissions related to trip volumes but not to trip lengths or speeds amount to approximately one-quarter of total carbon monoxide (CO) emissions and about 15 percent of total hydrocarbon (HC) emissions.

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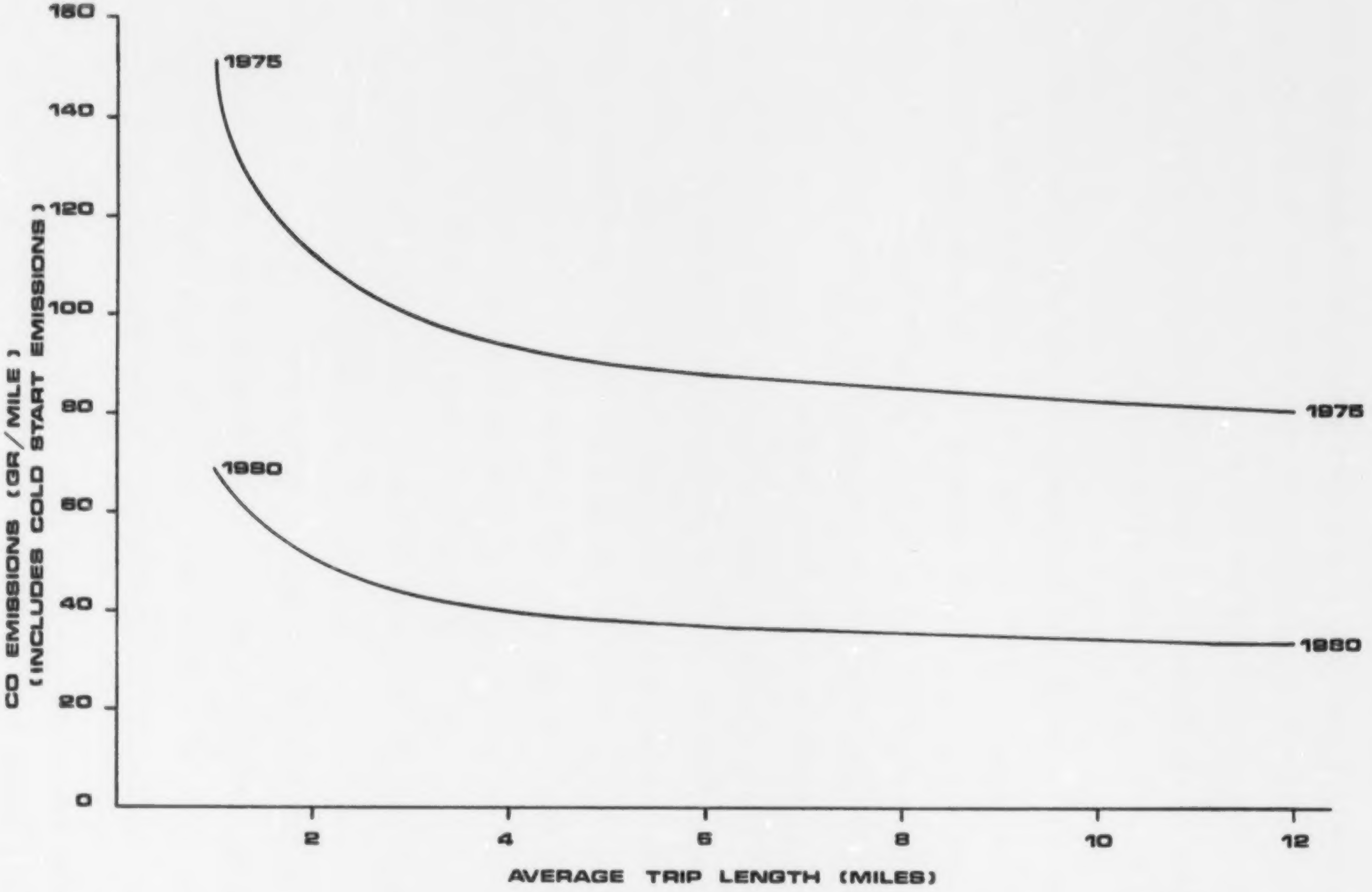
[1] Argonne National Laboratory. Handbook of Air Pollutant Emissions from Transportation Systems. Prepared for Illinois Institute for Environmental Quality, December, 1973.

[2] Horowitz, J. L. and L. M. Pernela. "Comparison of Automobile Emissions According to Trip Type in Two Metropolitan Areas." Presented at 54th Annual Meeting of the Transportation Research Board, January, 1975. Also, Horowitz, J. L. and L. M. Pernela. "An Analysis of Urban Area Automobile Emissions According to Trip Type," in Transportation Research Record No. 492, 1974.

These results have particular significance when considering transit trip characteristics. First, it is expected that a high proportion of auto trips diverted to new transit service would include elimination of cold start emissions. To illustrate this rationale, 1972 survey data for Washington, D. C. bus trips showed that 69 percent of daily trips were for work purposes. Assuming that all work trips and that about 40 percent of the remainder involve cold starts, an estimated 81 percent of all bus trips if made by auto would involve cold starts. Similar data for other metropolitan areas shows that between 70 and 90 percent of all diverted auto trips would have cold starts. Consequently, transit trips may represent a potentially higher payoff for air quality improvement due to elimination of work trips involving cold starts at both the home and work trip ends. Second, use of an automobile for transit system access trips amy lesses potential reductions in CO and HC emissions due to the occurrence of cold start and HC evaporative emissions emitted in the vicinity of the point of transit system access. In Figure 2.1, emission factors are plotted as a function of trip length for a suburban trip including a cold start. For trip lengths shorter than 2-3 miles, the cold start may have a pronounced effect. Results of case study analyses will illustrate that this does occur and may serve to worsen air quality conditions in suburban areas although overall corridor improvements are obtained.

Cold start emission factors for 1975 vehicle fleet characteristics were developed using Argonne National Laboratory estimates of cold start emissions



2.1

CO EMISSION RATES VS. AUTO TRIP LENGTH

(grams/vehicle) for new cars for each model year from 1960 to 1975. These unit values were subsequently weighted by the percent of each model year making up the 1975 national fleet with correction for deterioration of control equipment.[1]

2.2.1.2 Diverted Auto Driving Cycles

The Federal Test Procedure employs a driving cycle lasting 23 minutes and covering 7.5 miles. It includes multiple stops with cruising portions resulting in an average speed of about 20 miles per hour. To more accurately capture diverted auto trip characteristics, auto driving cycles were developed for suburban, corridor, and urban travel with variations involving average speeds and number of stops. Emission factors for component pieces of each cycle were obtained from A Study of Emissions From Light Duty Vehicles in Six Cities.[2]

A comparison with equivalent Environmental Protection Agency CO emission factors (corrected for zero percent cold starts and average speed) indicates that correcting for different driving cycle conditions within metropolitan areas can make a difference of up to 30-40 percent (see Table 2.4). Using EPA speed and fleet composition adjustment factors and the set of ratios tabulated in Table 2.4, representative 1975 CO emissions factors were developed for each driving cycle. These estimates are summarized in Table 2.5. For HC emissions estimation, average EPA unit factors for exhaust emissions were utilized and driving cycle corrections were not made.

2.2.1.3 Bus Air Pollutant Emissions

Data on the air pollutant emission rates of diesel-powered buses is not

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[1] Calspan Corporation. Automobile Exhaust Emission Surveillance, A Summary. Prepared for the Environmental Protection Agency, May, 1973.

[2] Automotive Environmental Systems, Inc. A Study of Emissions From Light Duty Vehicles in Six Cities. Prepared for the Environmental Protection Agency, March, 1973.

TABLE 2.4

COMPARISON OF DRIVING CYCLE AND FEDERAL TEST PROCEDURE CO EMISSION FACTORS

Driving Cycle	Average Speed (mph)	Average Emissions (g/mi)	FTP[a] Emissions (g/mi)	Ratio of CO Emissions Factors
Suburban	17.6	63.1	59.9	1.1
	13.0	96.3	76.5	1.3
	9.7	129.4	99.4	1.3
Corridor	43.9	29.5	27.7	1.1
	31.0	46.4	37.1	1.3
	23.5	65.1	46.9	1.4
Urban	11.3	90.9	87.0	1.0
	7.8	138.1	119.4	1.2
	5.9	185.4	151.0	1.2

Note: (a)Corrected for zero percent cold starts and average speeds.

Source: TRW Environmental Services

TABLE 2.5

AVERAGE 1975 CO EMISSION FACTORS WITH DRIVING CYCLE CORRECTION

Driving Cycle	Grams/Mile
Suburban	47 - 103
Corridor	27 - 55
Urban	45 - 128

Source: TRW Environmental Services

widely available. For this study, the values listed in Table 2.6 were identified and used to define ranges for suburban, corridor, and urban operations for model input.

Due to the nature of the diesel engine, different parameters are involved in producing emissions. Diesel engines run at higher efficiencies and temperatures utilizing more oxygen than do light duty gasoline engines. Therefore, they produce less CO and HC, and more NO_x on a per mile basis than do light duty vehicles. One of the major parameters effecting these emissions is the fuel injection system. In 1970, a new injector (called a "N" injector) was introduced which served to reduce the amount of fuel entering the cylinder. These injectors were adopted by older diesel engines in order to conserve fuel. As a consequence of this fuel conservation measure, diesel engine emissions were also reduced. No analysis of emissions of either nitrogen or sulfur compounds were carried out as part of this study.

2.2.1.4 Rail Transit Air Pollutant Emissions

Electric vehicles have no direct emissions. Their contribution to air pollution stems from additional loads placed upon the power plants serving the system. Furthermore, power plants do not contribute significantly to CO, or HC emissions totals in urban areas. However, power plants may be a major source of particulates (TSP), NO_x, and sulfur dioxide (SO_2) pollutants depending on how the plant is fueled. Analysis relating to the potential air pollution impacts of BART and the Lindenwold rapid transit line are summarized in Chapter 5 of this report.

2.2.2 AUTO AND TRANSIT UNIT ENERGY CONSUMPTION CHARACTERISTICS

Direct automobile gasoline consumption characteristics have been well researched and reported. Figure 2.2 shows the range of auto gasoline consumption rates employed

TABLE 2.6

BUS AIR POLLUTANT EMISSION FACTORS

(GRAMS PER MILE)

Source	Carbon Monoxide	Hydrocarbons
EPA Heavy Duty Vehicle (5 mpg)(a)	20.4	3.4
Argonne Heavy Duty Vehicle (3 mpg)(b)	32.5	n/a
Environmental Protection Agency(c)		
Arterial	15.0	3.8
Downtown	28.8	7.2
Department of Transportation(d)		
Express Bus	10.5	11.7
Other	10.9	14.7

References: (a) U. S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, Second Edition, AP-42. September, 1973.

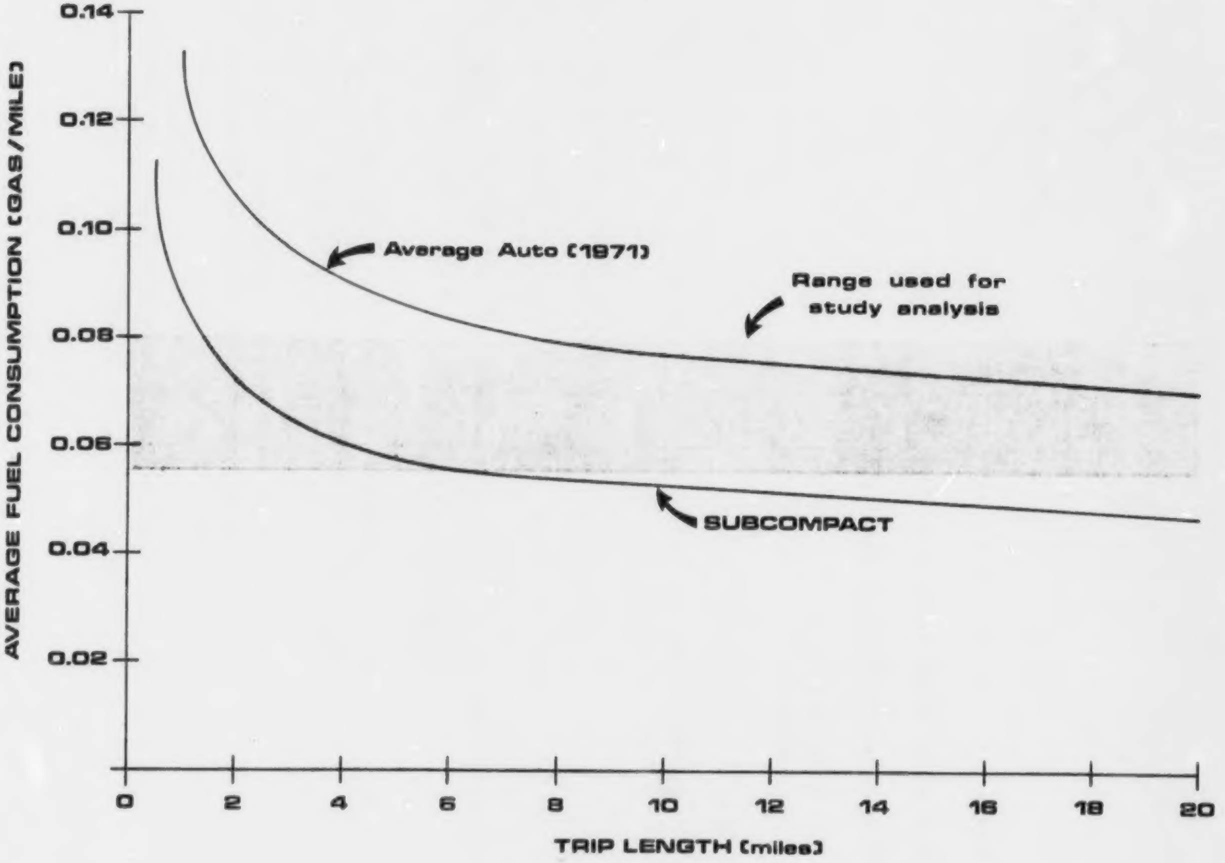
(b) Argonne National Laboratory. Handbook of Air Pollutant Emissions from Transportation Systems. Prepared for Illinois Institute for Environmental Quality, December, 1973.

(c) Communication with Mr. D. Syskowski citing preliminary data for 1971 model year coach supplied by General Motors Corporation.

(d) U. S. Department of Transportation. Characteristics of Urban Transportation Systems. May, 1974.

2.2

AUTO GASOLINE CONSUMPTION



for study simulation analyses. Data prepared by Hirst[1] for standard and compact autos using Federal Highway Administration data summaries is plotted for comparison.

For this study, special attention was directed towards three aspects which appeared not to have received thorough consideration in previous research studies:

- Effect of improved auto efficiency on potential energy savings due to diversion of auto trips to transit;
- Identification of key factors affecting transit system energy consumption characteristics; and
- Comparison of indirect energy use of auto and transit systems.

2.2.2.1 Improved Auto Efficiency

Several recent studies have concluded that means for improving automobile fuel consumption efficiency offers substantial short-term (via carpooling) and longer-term (via propulsion system and auto design improvements) potential for transportation energy conservation. In view of current auto dependency amounting to approximately 98 percent of total urban passenger travel by auto, the basis for significant reductions in energy use through improved efficiency is apparent.

Whether or not this strategy is able to realize its potential effectiveness without additional means of controlling dispersed land development trends, which have historically accompanied increasing auto use, is a companion issue which has not been fully addressed to date. Recently-completed research studies at Northwestern University and Princeton University suggest that additional land use controls are required if long run energy consumption is to be reduced to within national supply limitations projected for future years. For the time being, national policy appears limited to goals related to improved auto efficiency as the primary thrust for energy conservation in the transportation sector. On-going major research programs regarding national energy source development by the Federal Energy Administration, Environmental Protection Agency, and others should provide final directions and guidance in this regard.

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[1] Hirst, E. Direct and Indirect Energy Requirements for Automobiles. Oak Ridge National Laboratory, February, 1974.

To evaluate the impact of imrpoved auto efficiency on the relative energy attractiveness of new transit system developments, the net energy consumption change associated with each case study was also estimated assuming that auto gasoline consumption rates improved by forty percent. As will be reported in subsequent chapters, net energy consumption reductions are considerably smaller and consumption increase conditions more pronounced.

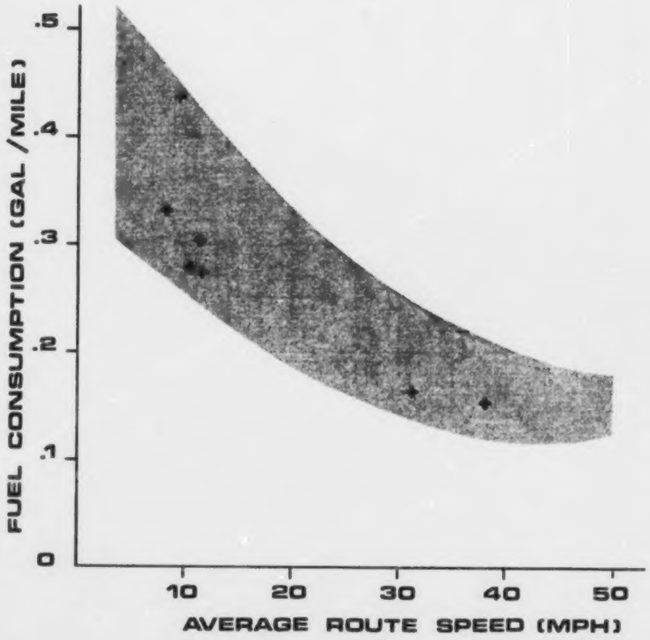
2.2.2.2 Bus Energy Consumption Characteristics

In Figure 2.3, average bus fuel consumption recorded for seven bus lines operated in San Francisco and Los Angeles is summarized. Note that express bus service operating with few stops on free-flowing freeway lanes results in significantly lower fuel consumption than local bus service operating at slower average speeds with regularly-spaced stops. For planning purposes, use of average bus fuel consumption data which primarily reflects local service operations may provide significantly high estimates of actual fuel consumption rates for new express service operations. Model analysis carried out as part of this study incorporated unit consumption values which accounted for different operating conditions.

Average route speed is highly dependent on bus stop spacing policy. In Figure 2.4, the same bus fuel consumption data is plotted as a function of average number of stops per mile. This data illustrates that express bus operations may

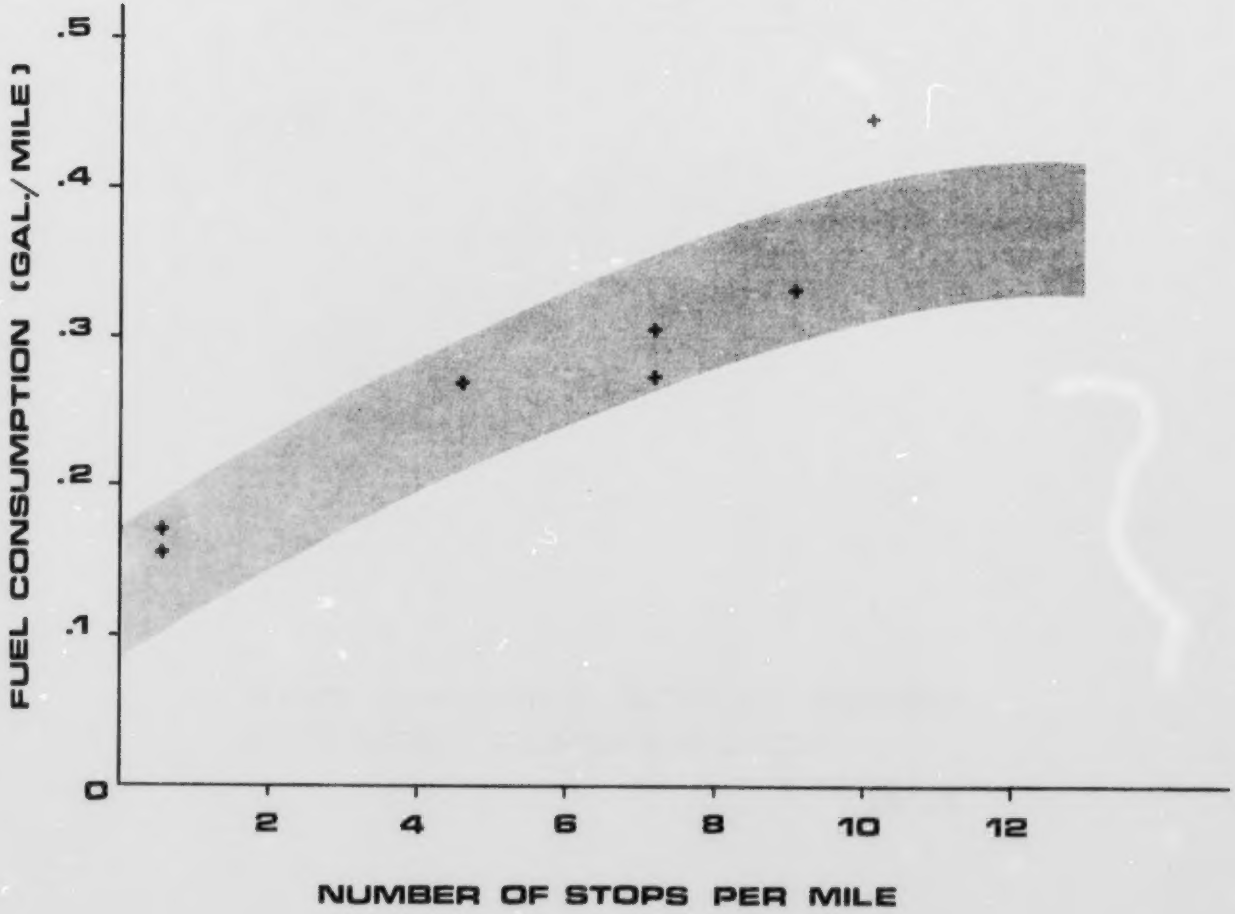
2.3

BUS FUEL CONSUMPTION AND AVERAGE ROUTE SPEED



2.4

BUS FUEL CONSUMPTION AND BUS STOP FREQUENCY



result in significantly improved fuel consumption in comparison with local bus service operations and overall system average values.

2.2.2.3 Rail Transit Energy Consumption

As a starting point, six components of total rail transit energy consumption may be distinguished:

- propulsion energy required to move vehicles over the guideway;
- vehicle accessories energy for heating, air conditioning, and lighting;
- station energy required to provide station heating, lighting, information, and parking as well as administrative operations;
- maintenance energy associated with the upkeep and repair of vehicles and other system equipment and facilities;
- construction energy to build the entire system including guideways, terminals, vehicles, and administrative and maintenance facilities; and
- impact energy due to transit-related development not part of the system itself.

To simplify, transportation energy use may be considered as consisting of direct and indirect components. For rail transit, direct energy consists of vehicle propulsion and accessory energy consumption while indirect energy includes station, maintenance, construction, and impact energy components.

A pair of recent studies have analyzed in some detail the direct and indirect energy consumption characteristics of BART and of the Lindenwold rail transit line. Healy has derived estimates of five energy use components including construction energy but not impact energy.[1] Boyce and Noyelle have estimated the first four energy components listed above for the Lindenwold under a recently-completed study for the Federal Energy Administration.[2] Both results are summarized in Table 2.7 for comparison.

These are substantial inefficiencies associated with electrical power generation (from petroleum, fossil fuel, and other energy sources) and distribution. Estimates of point-of-use/source energy vary between 0.30 and 0.35.[3] In other words, a unit of source fuel with an energy equivalent of 100 BUT's will contribute 30-35 BTU's of electrical energy for vehicle propulsion or other purposes. There are also energy losses associated with the refining of source petroleum fuels for gasoline and diesel fuel, amounting to source/point-of-use ratio of approximately 0.9. For this study, all energy analyses are expressed in terms of equivalent gallons of refined petroleum fuels. Electrical energy use has been converted to equivalent gallons with appropriate factors employed to reflect energy losses.

Direct rail transit energy requirements are dependent on a number of factors relating to system design and performance characteristics including the following:

- vehicle weight
- vehicle performance

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[1] Healy, T. J. "Energy Requirements of the Bay Area Rapid Transit (BART) System." Prepared for the State of California Department of Transportation, November, 1973.

[2] Boyce, D. C. and T. Noyelle. "The Energy Consumption of the Philadelphia-Lindenwold High-Speed Line and Other Modes of Transportation in the South Jersey Corridor." Preliminary Draft Report prepared for the Federal Energy Administration, January, 1975.

[3] Healy, op. cit. Also Lansing, N. F. and H. R. Ross. Energy Consumption by Transit Mode. Prepared for the Southern California Association of Governments, March, 1974

TABLE 2.7

COMPARISON OF ESTIMATED ENERGY USE COMPONENTS

	BART(a)		Lindenwold(b)	
	KWH/CM	Percent Of Propulsion Energy	KWH/CM	Percent Of Propulsion Energy
Propulsion	4.0	100	6.1	100
Vehicle accessories (lighting, heating, air conditioning)	0.5	13	1.2	20
Regenerative braking	up to (-0.8)	(-20)	-	-
Live vehicle storage	0.5 - 1.0	13 - 26	-	-
Stations, maintenance	1.8 - 2.4	45 - 60	2.0	33
TOTAL	6.0 - 7.9		9.3	

Sources: (a) Healy, *op. cit.*

(b) Boyce and Noyelle, *op. cit.*

- propulsion control system
- station spacing
- vehicle loading
- vehicle accessories

In-depth discussion of each factor is available in a number of engineering references and planning analysis reports.[1] One example may serve to illustrate tradeoffs involved in system design. If transit cruise speeds were lowered from 80 miles per hour, which modern rail transit vehicles are designed to attain, to 50 miles per hour, source energy requirements per car-mile would be reduced by over one-half. This change would cause the average line haul speed to be reduced from 39 mph to 33 mph, or for a ten-mile journey, a difference of nearly three minutes in travel time. This represents about a 15 percent change in overall line haul travel time, which would generate an expected patronage loss of approximately six percent.[2] However, it would also be necessary to increase the vehicle fleet size by 10-15 percent to maintain equivalent line haul service frequencies and seated passenger capacity which would add to total energy utilization. In summary, the example performance change would reduce total energy consumption by approximately 35-40 percent with an estimated six percent ridership decrease and 10-15 percent increase in the transit vehicle fleet size.

For rail transit systems, indirect energy use includes energy for stations, maintenance, system construction and related items.

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[1] For example, see Smylie, J. S. "Energy Consumption of Alternative Transport Modes -- Bus, Light Rail, Conventional Rail, Group Rapid Transit, and Personal Rapid Transit." Prepared for the Third Intersociety Conference on Transportation, Atlanta, July, 1975.

[2] Applying a direct elasticity value of -0.39 reported by Charles River Associates, An Evaluation of Free Transit Service (1968) using Boston data.

Stations and Maintenance

For BART system stations and maintenance energy categories, Healy reports estimated energy consumption equal to approximately 40 percent of direct energy utilization for vehicle propulsion, accessories, and live storage. This value is based on full system operations. Boyce and Noyelle estimate that station and maintenance energy for the Lindenwold rail transit line amount to an additional 25-30 percent of direct energy consumption, comparable with Healy's data for BART although no allowance has been made for live vehicle storage. These relationships may be viewed as approximations for planning purposes. Energy consumption characteristics for stations, maintenance and related non-vehicle system facilities are dependent on a variety of design factors and not necessarily proportional to direct energy requirements to any significant degree.

Construction

Healy has also derived an estimate for BART construction energy, determining that it is approximately equal to source energy requirements for vehicle propulsion, accessories and live storage over a 50 year period. For the assumed 50 year lifespan:

Direct Energy	1.0×10^{14} BTU
Indirect Energy	
stations, maintenance	0.4×10^{14} BTU
construction	1.1×10^{14} BTU

The estimate was developed by applying 1963 energy/GNP dollar coefficients developed by Herendeen[1] for each sector of the economy to the dollar amount of materials/services in each sector required for BART construction. Based on studies of the energy required to manufacture unit quantities of materials used for guideway and vehicle construction, Fels has estimated construction energy for BART guideway and cars to be approximately 25 million KWH per single guideway mile and 1.2 million KWH per car respectively.[1] Applying these estimates for full system development over a 50 year period for comparison with Healy's data results in a construction energy total of approximately 0.4 - 0.5 x 10^{14} BTU or about one-half of Healy's estimated total. Thus, two independent approaches to estimating transit system construction energy result in two different findings--one placing construction energy approximately equal to direct system energy utilization and the second about one half of this amount.

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[1] Herendeen, R. A., An Energy Input-Output Matrix for the United States, 1963. University of Illinois, Urbana. 1973.

Hirst has developed estimates of direct and indirect energy requirements for automobiles using updated energy/GNP dollar coefficients by Herendeen[2], the same approach employed by Healy for estimating BART total energy components. From Table 2.8 which summarizes Hirst's findings, indirect automobile energy equals approximately 60 percent of direct automobile energy for propulsion and vehicle accessories. Of this total amount, construction energy is equivalent to about 22 percent of direct energy or from two to four times less than for rail transit construction. In Summary,

	Auto[3]	Rail Transit[3]
Direct Energy	100	100
Indirect Energy		
Maintenance, System Facilities	40	25-40
Construction	22	50-100

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[1] Fels, N.F. Comparative Energy Costs of Urban Transportation Systems. Transportation Program Report, Princeton University. September, 1974.

[2] Hirst, E. Direct and Indirect Energy Requirements for Automobiles.

[3] Expressed as percentage of direct energy consumption for vehicle propulsion and accessories.

Table 2.8

TOTAL AUTOMOBILE ENERGY USE, 1971

Function	Dollar Cost ($/VM)	Energy Coefficient (Btu/$)	Energy use (Btu/VM)	Total Energy Use (10^{12} Btu)	Total Energy Use % of Total
Gasoline					
consumption	--	--	9,900	9,500	60
refining	0.008	0.208[(a)]	2,100	2,000	13
transport, sale	0.009	37,000	400	300	2
Oil	0.002	--	100	100	1
Automobile					
manufacture	0.023	55,000	1,300	1,200	8
transport, sale	0.009	29,000	300	200	1
Repairs, maintenance, parts	0.016	27,000	400	400	2
Tires	0.004	60,000	200	200	1
Insurance	0.017	25,000	400	400	3
Parking, garaging, tolls	0.018	27,000	500	500	3
Taxes (highway construction)	0.014	78,000	1,100	1,000	6
Totals	0.120		16,700	15,800	100

Note: (a) Btu/Btu
Source: Hirst, p. 13.

consider the implications of this difference if, in fact, the report estimates of indirect energy use are correct in their relative magnitude. Using Lansing and Ross' estimates of average source energy consumption per passenger mile for transit and auto modes[1]:

	Btu per passenger mile Auto	Rail Transit
Direct Energy	8,360	5,240
Indirect Energy		
Maintenance, System Facilities	3,340	1,300-2,100
Construction	1,840	2,620-5,240
TOTAL	13,540	9,160-12,580

At the upper bound level for rail transit indirect energy elements, the difference between transit and auto energy consumption on a passenger-mile basis using average vehicle load factors is not large. While this is a significant conclusion especially when considered in conjunction with our other findings regarding total transit system energy consumption (including, for example, access requirements), it should be cautioned that the reported methodologies have employed aggregate data summaries and varying approaches for lifetime amortization. Further research is needed to verify the magnitude of indirect energy use differences and clarify available results.

2.2.3 RIDERSHIP RESPONSE TO NEW TRANSIT SERVICES

The case studies examined in this project involved a variety of new transit service types, each offering a different degree of attractiveness for competition with auto travel. Estimating ridership response to new transit services is a difficult task and becomes particularly difficult for bus service improvement programs involving route extensions, increased service frequencies, new lines, public information and marketing, and new equipment such as for case studies in Atlanta, Washington, San Diego, and Orange County[1]. There is considerable data regarding observed ridership elasticities to fare changes and, additionally, much on-going and recent research concerning new corridor transit services offering high levels of service. However, relationships describing potential ridership of areawide bus service improvement programs are not well established. For this study, actual ridership response data was utilized although it was necessary to rely on default relationships based on limited case study data for new rider characteristics data including former mode of travel. As will be reported in later chapters, further research is required to establish the characteristics of trips diverted to transit to fully assess transit's energy consumption and air pollutant emissions impacts.

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[1] Lansing and Ross. Energy Consumption by Transit Mode. Using 0.25 vehicle load factor.

2.2.3.1 Short-Term Changes in Travel Behavior

It has generally been observed that ridership response to new transit service will stabilize within three months of its initial introduction. Within this period, individuals may elect to use it under one or more of three conditions.

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[1] Holland, D. K. A Review of Reports Relating to the Effect of Fare and Service Changes in Metropolitan Public Transportation Systems. Prepared for the Federal Highway Administration, June, 1974.

Make a Trip Not Previously Made

These trips do not contribute to any reductions in energy use or air pollution levels. "induced" or "latent" demand for transit service is an item not well understood. Household trip-making has generally been treated as being independent of transportation system characteristics, and little research has been applied to studying latent travel demand characteristics.

Shift From Using an Automobile

This group of new service users will generate air pollution and energy consumption reductions to the extent that the amount of automobile travel is reduced or eliminated (minus the increases due to new transit services). The degree of impact may be increased if the reductions in auto trip-making occur in heavily-travelled corridors during peak periods, resulting in improved auto travel speeds and less traffic congestion. On the other hand, net energy consumption savings and air pollutant emissions reductions may be lessened to the extent that:

- automobiles not used as a result of shifting to transit are employed for other trips by other household members; and

- new transit users may make an automobile trip to reach the new transit system, either to park and ride or as an auto passenger to be dropped off.

Urban area transit trips are generally shorter on the average than auto trips, reflecting a combination of generally poorer transit service levels in outlying areas, greater opportunities and propensity for auto travel in suburban areas, and other factors. The degree to which new transit services continue to attract relatively shorter trips will influence potential energy consumption savings and air pollutant emissions reduction amounts.

Shift From Other Modes

Passengers diverted from other transit modes, from traveling as an auto passenger, and in some cases perhaps from bicycle and walk modes, may provide some overall reductions in system energy utilization and air pollution to the extent, if any, that new transit services are less energy and pollution intensive than former modes. It appears that diversion of persons traveling as auto passengers is the most critical element of this issue. Furthermore, shifts from carpooling to new services recently or currently being implemented must be interpreted in view of existing low auto occupancy and carpooling activities. Increased attention to the potential benefits of large-scale carpooling utilization suggests that the issue of competition between transit and carpooling as alternatives to the automobile cannot be answered from analysis of available experience.

2.2.3.2 Long-Term Changes in Travel Behavior

Over a longer period of time, the introduction of new transit services may generate changes in household trip-making characteristics with substantial energy consumption and air quality implications. These changes are related to:

- reduced automobile ownership; and

- shifts in residence locations and other land uses.

Major decisions of this type are dependent on many social, economic, and environmental concerns in addition to accessibility and it becomes difficult to distinguish what should be attributed to development of new transit service and what would have occurred in any case.

The decision to replace or purchase an automobile should be influenced by the availability of improved transit services. A reduction in automobile ownership levels due to new transit system development and availability is able to generate substantial savings in total household transportation costs, and provide a key basis for new system justification. For purposes of this study, auto ownership reductions are especially significant as the longer range basis for achieving energy consumption and air quality goals. Table 2.9 shows the variation in daily household auto trips as a function of household auto ownership from available data summaries. While this tabulation does not account for other key household characteristics (e.g., size, number of employed persons, income) which affect both trip generation and auto ownership, it does suggest the potential for reductions in vehicle miles traveled accompanying reduced auto ownership levels. To date there has been little research into measuring how increased transit accessibility influences household auto ownership. A recent study by Dunphy using the 1968 home interview data collected by the Metropolitan Washington Council of Governments identified statistically significant relationships between transit accessibility and household auto ownership.[1] Further analysis of this important area is required.

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[1] Dunphy, R. T. "Transit Accessibility as a Determinant of Automobile Ownership." Paper presented at the 52nd Annual Meeting of the Highway Research Board, January, 1973.

TABLE 2.9

DRIVER TRIPS IN MULTI-CAR HOUSEHOLDS

NUMBER OF CARS	AVERAGE DRIVER TRIPS	STUDY AREA				
		CHICAGO (1956)	NASHVILLE (1959)	SAN FRANCISCO BAY (1965)	PUGET SOUND (1961)	SACRAMENTO (1968)
One	Driver Trips	2.99	4.70	3.97	4.19	4.2
	Average Per Car	2.99	4.70	3.97	4.19	4.2
	Average First Car	2.99	4.70	3.97	4.10	4.2
Two	Total Driver Trips	5.92	8.24	6.58	7.45	n/a
	Average Per Car	2.96	4.12	3.29	3.73	3.3(1)
	Average Per Second Car	2.93	3.54	2.61	3.26	2.4(3)
Three	Total Driver Trips	8.57	11.00	9.03	10.05	---
	Average Per Car	2.86	3.68	3.01	3.35	---
	Average Per Third Car(2)	2.65	2.76	2.45	2.60	---

(1) Assumes first car averages same number of trips as one-car households.

(2) Assumes first and second cars average same number of trips as in two-car households.

(3) Average for second plus third cars.

Source: Origin-destination studies in each area; Future Highways and Urban Growth, Wilbur Smith & Associates.

CHAPTER 3

EXPANDED REGIONAL BUS SERVICE

3.1 INTRODUCTION

Throughout the nation, metropolitan areas have been improving bus service levels on a region-wide basis. Due to lower average fares (Figure 3.1) increased bus-miles of service (Figure 3.2), and new bus equipment (Figure 3.3), and spurred by last winter's fuel shortage conditions, bus ridership has swung in an upward direction after thirty years of steady decline (Figure 3.4). The availability of operating subsidy assistance under provisions of the 1974 Mass Transportation Act should serve to further stimulate bus service expansion and continue the momentum of current trends in coming years.

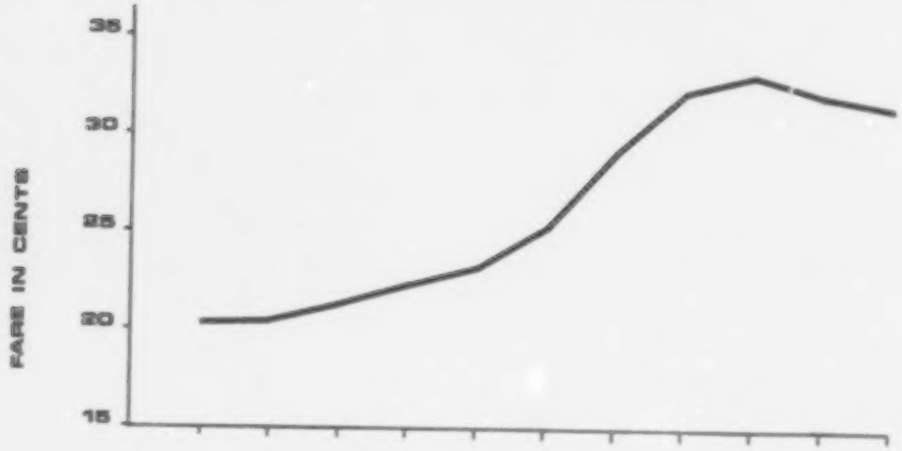
Study analyses presented in this chapter address the energy conservation and air quality impacts of regional bus service improvements. Specifically, three types of service improvements have been analyzed:

- fare reductions;
- increased bus-miles of service due to new routes, route extensions, and headway reductions; and
- demand actuated service (dial-a-ride).

Data inputs have been derived primarily from five case studies although numerous other references, and data summaries maintained by the American Public Transit Association have been employed as well. The case studies involve:

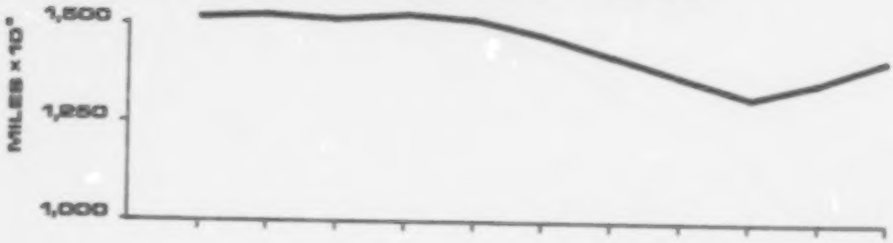
3.1

TREND OF AVERAGE FARE



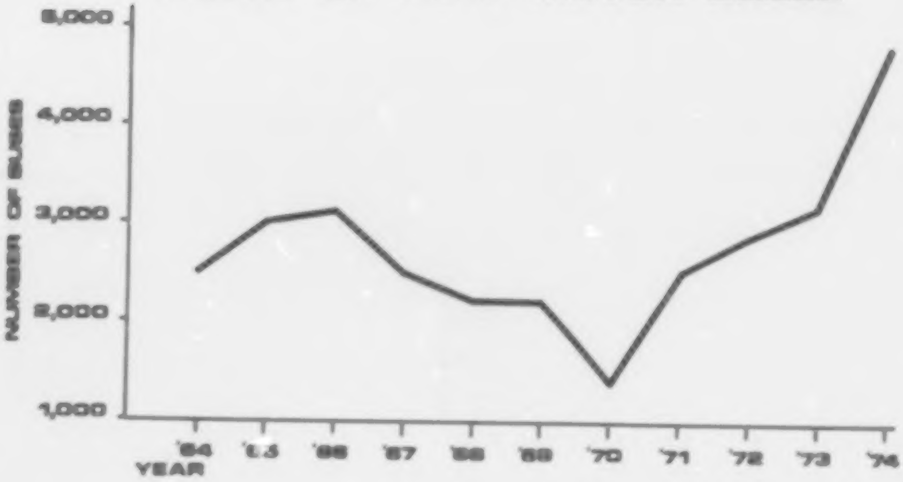
3.2

TREND OF VEHICLE MILES



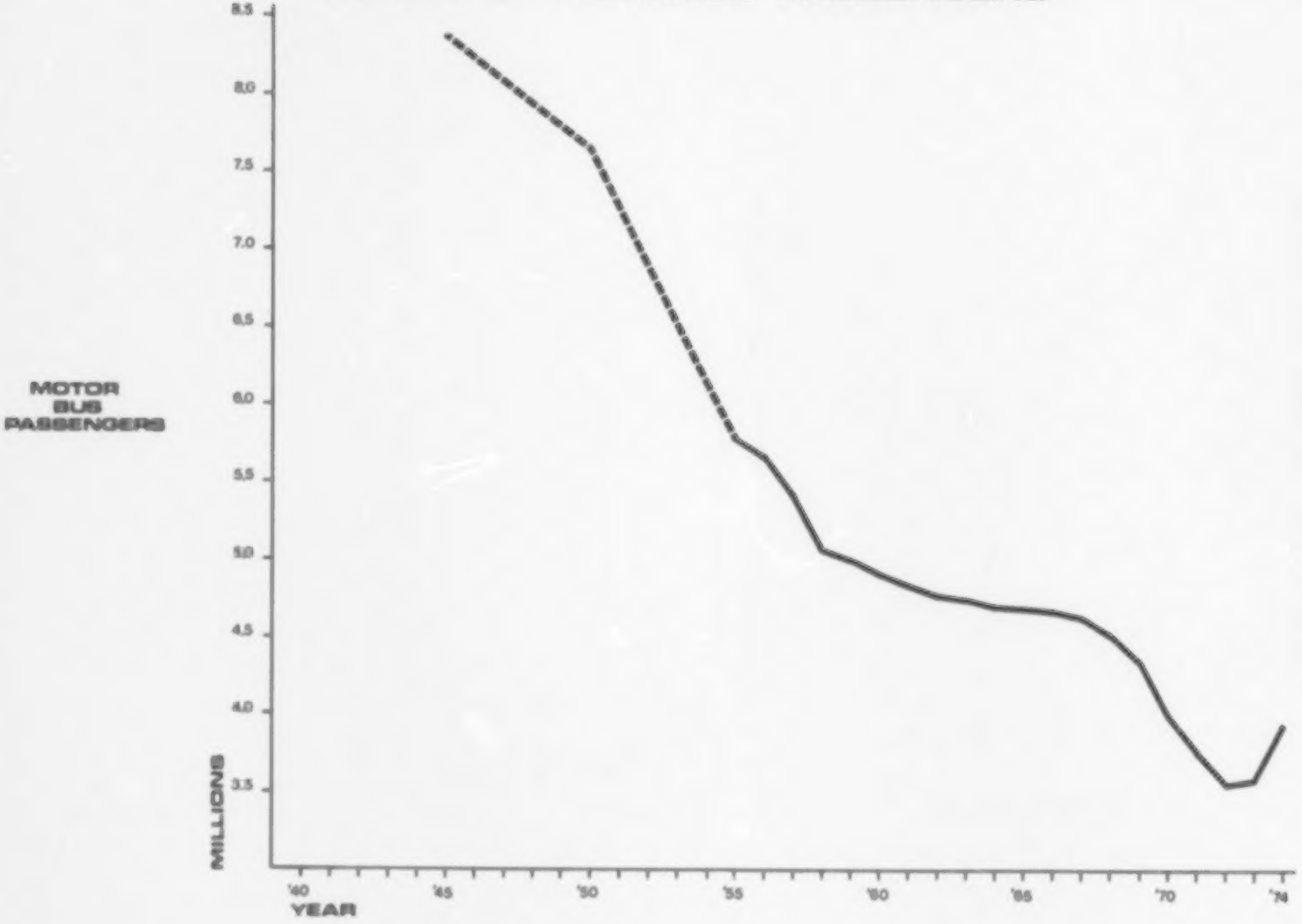
3.3

TREND OF NEW MOTOR BUSES



3.4

TREND OF REVENUE PASSENGERS



	Fare Reduction	Increased Bus-miles	Demand Actuated
Atlanta	X	X	
San Diego (I)	X	X	
(II)		X	
Washington		X	
Orange County, California			X

Table 3.1 summarizes selected operating characteristics and 'before' and 'after' conditions for each of the case studies.

3.1.1 METHODOLOGY

The model developed for studying the impact of expanded regional bus service using input data from each of the five case studies incorporates key factors as noted in Table 3.2 A detailed flow chart is included in Appendix A.

Data limitations have required two key assumptions to be invoked. Data regarding the prior travel mode of new bus service users was only available for the Atlanta case study and it was utilized for the other four cases as well. In addition, the number of diverted auto trips was treated parametrically for other case studies. A second assumption was required to estimate diverted auto trip lengths. Average trip length relationship based on regional population provided a basis for estimating the modal value for diverted auto trip lengths, with lower and upper bounds assumed to be 80 percent and 110 percent of the modal trip length.

Auto and bus fuel consumption rates and air pollutant emissions factors are incorporated as random variables in the model. Modal, lower bound, and

TABLE 3.1

SELECTED OPERATING DATA FOR CASE STUDIES

Case Study	Approximate Population (millions)	BEFORE Daily Bus miles (thousands)	BEFORE Daily Ridership (thousands)	BEFORE Base Fare (cents)	AFTER Daily Bus miles (thousands)	AFTER Daily Ridership (thousands)	AFTER Base Fare (cents)
Atlanta (1972)	1.6	64	185	40	75	237	15
Washington (1973-74)	3.0	159	433	40	185	456	40
San Diego (1972)	1.4	27	51	40	35	82	25
San Diego (1974-)	1.4	35	82	40	58	104	25
Orange County (1974)	1.5	-	-	-	21	24	25-50

TABLE 3.2

FACTORS AFFECTING ENERGY CONSUMPTION AND AIR POLLUTANT EMISSION CHANGES DUE TO EXPANDED REGIONAL BUS SERVICE

		DATA AVAILABLE						MODEL ANALYSIS				
		ATLANTA	WASHINGTON	SAN DIEGO	SAN DIEGO	ORANGE COUNTY	OTHER	INPUT	RANDOM VARIABLE	PARAMETRIC ANALYSIS	OUTPUT	BREAKEVEN
LEVEL OF BUS SERVICE	NEW BUS-MILES OF SERVICE	●	●	●	●	●		●				
	FARE CHANGE	●		●				●				
BUS RIDERSHIP	NEW RIDERSHIP	●	●	●	●	●		●				
	LOAD FACTOR	●	●	●	●	●	●					
	PREVIOUS TRAVEL MODE INCLUDING DIVERSION FROM CARPOOLS	●										
AUTO TRIP DIVERSION	NUMBER OF AUTOS DIVERTED	●							●	●		●
	DIVERTED AUTO TRIP LENGTH						●		●	●		●
	TIME OF DAY OF DIVERTED AUTO TRIPS	●										
	REGIONAL LOCATION OF DIVERTED AUTO TRIPS		●									
	DIVERTED AUTO UNIT GASOLINE CONSUMPTION						●		●	●		●
	DIVERTED AUTO UNIT EMISSIONS						●		●	●		●
	BUS UNIT FUEL CONSUMPTION						●		●	●		●
	BUS UNIT EMISSIONS						●		●			
OUTPUT	NET 1975 CO EMISSIONS REDUCTION										●	
	NET 1975 HC EMISSIONS REDUCTION										●	
	NET 1975 FUEL SAVINGS										●	
	NET FUEL SAVINGS WITH IMPROVED AUTOS										●	

upper bound values were estimated according to the methodology described in Chapter 2. All energy savings have been expressed in terms of equivalent gallons of refined gasoline.

From data in Table 3.1, four case studies provide estimates of ridership elasticity to increased bus-miles of service, i.e., $\frac{\Delta \text{ridership}}{\Delta \text{bus-miles}}$ as follows:

Atlanta	0.6-1.3*
Washington	0.3
San Diego (1973)	1.7-1.9*
San Diego (1975)	0.4

The values noted with an asterisk have been discounted for the expected effect of concurrent fare reductions.[1,2] It seems that fare reductions may have had a greater impact than would be expected by application of historical relationships. With regard to system load factors, an elasticity value of less than one means that the service improvements have resulted in a lower system load factor than for before the improvements were made.

3.2 ATLANTA

Following initiation of public transit operations in the Atlanta metropolitan area in early 1972, passenger fares were lowered from a previous base fare of 40 cents to 15 cents. This reduction generated substantial new ridership, requiring the acquisition on an emergency basis of used buses from other transit operations to be reconditioned and put into service to relieve passenger overloads. Through November 1972, a total of 117 service changes were made

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[1] Holland, D. K. A Review of Reports Related to the Effect of Fare and Service Changes in Metropolitan Public Transportation Systems. Prepared for Federal Highway Administration, June 1974.

[2] Highway Users Federation. Transit Fare and Ridership: A Review, Dec. 1974.

which increased the annualized bus miles of operation from approximately 19 million at the date of acquisition to approximately 22 million annual bus miles of service. The service changes were made primarily in the area of improved headways and expanded service periods. There were 85 such changes, and in addition, 13 lines were extended, 14 lines were revised and five new lines were installed[1].

3.2.1 NEW RIDERSHIP

In response to the noted changes in bus service introduced in the Atlanta region, weekday bus ridership increased approximately 28 percent over the expected level. In this case, the expected level of ridership accounts for a continuation of the declining ridership trend experienced in preceding years. Discounting for this trend results in an average weekday ridership increase of approximately 13 percent.

There is extensive empirical data regarding patronage response to fare changes from numerous fare increases and, more recently, from fare reductions such as in Atlanta and San Diego. Applying this data, the Atlanta fare reduction of sixty percent (from 40 to 15 cents) would generate a 10-20 percent patronage gain. Consequently, the remaining 8-18 percent ridership increase may be attributed to the greater bus-miles of service, or expressed as an elasticity with respect to increased bus-miles:

$$E_{bm} = \frac{\Delta N/N}{\Delta BM/BM} = \frac{8\text{-}18}{14} = 0.6 - 1.3$$

In other words, a one percent increase in the number of bus-miles operated would generate an expected 0.6-1.3 percent increase in bus usage. The overall fare reduction program resulted in increased load factors for existing service, causing additional equipment to be deployed to accommodate heavier passenger loadings. However, ridership response to increased bus-miles operated (assuming bus trip lengths are constant or do not increase substantially) will serve to reduce the overall system load factor if the elasticity with respect to increased bus-miles is less than unity.

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[1] Metropolitan Atlanta Rapid Transit Authority. Analysis of Transit Passenger Data. October, 1973.

3.2.2 Diversion of Automobile Trips

Table 3.3 summarizes the previous travel mode of new bus riders as determined via an interview survey program following introduction of service improvements. Only 42 percent of the new bus trips had been previously made by automobile drivers, representing a total of nearly 22,000 auto trips removed from streets and highways each day. Significantly, over one-half of these former auto trips occurred during the morning and evening peak periods (see Table 3.4), and their diversion would be expected to relieve traffic congestion to generate possible secondary impacts on energy consumption and air pollutant emissions for remaining auto drivers.

The proportion of new transit riders diverted from auto passenger and walking modes should be noted. As shown in Table 3.3, approximately one-quarter of the new riders were attracted from these modes, both of which are already efficient from an energy consumption and air pollution standpoint. In addition, nearly 22 percent of the new transit trips were not made previously at all.

3.2.3 NET ENERGY CONSUMPTION SAVINGS

Figure 3.5 shows the output probability distribution of fuel savings due to the introduction of bus service improvements in the Atlanta region. The estimated mean fuel savings is approximately 9,300 gallons per day or less than one-half percent of regional daily fuel consumption for passenger transportation purposes. Savings varied from a 99-percentile lower bound of approximately 4,300 gallons to an upper bound of 13,100 gallons, reflecting uncertainty associated with auto trip diversion factors listed in Table 3.2.

TABLE 3.3

PREVIOUS TRAVEL MODE FOR ATLANTA NEW BUS RIDERS

Previous Mode	Number	Percent
Auto Driver	21,642	42
Auto Passenger	11,324	22
Walk	2,328	5
Other	5,343	10
No Trip	11,151	21
TOTAL	51,788	100

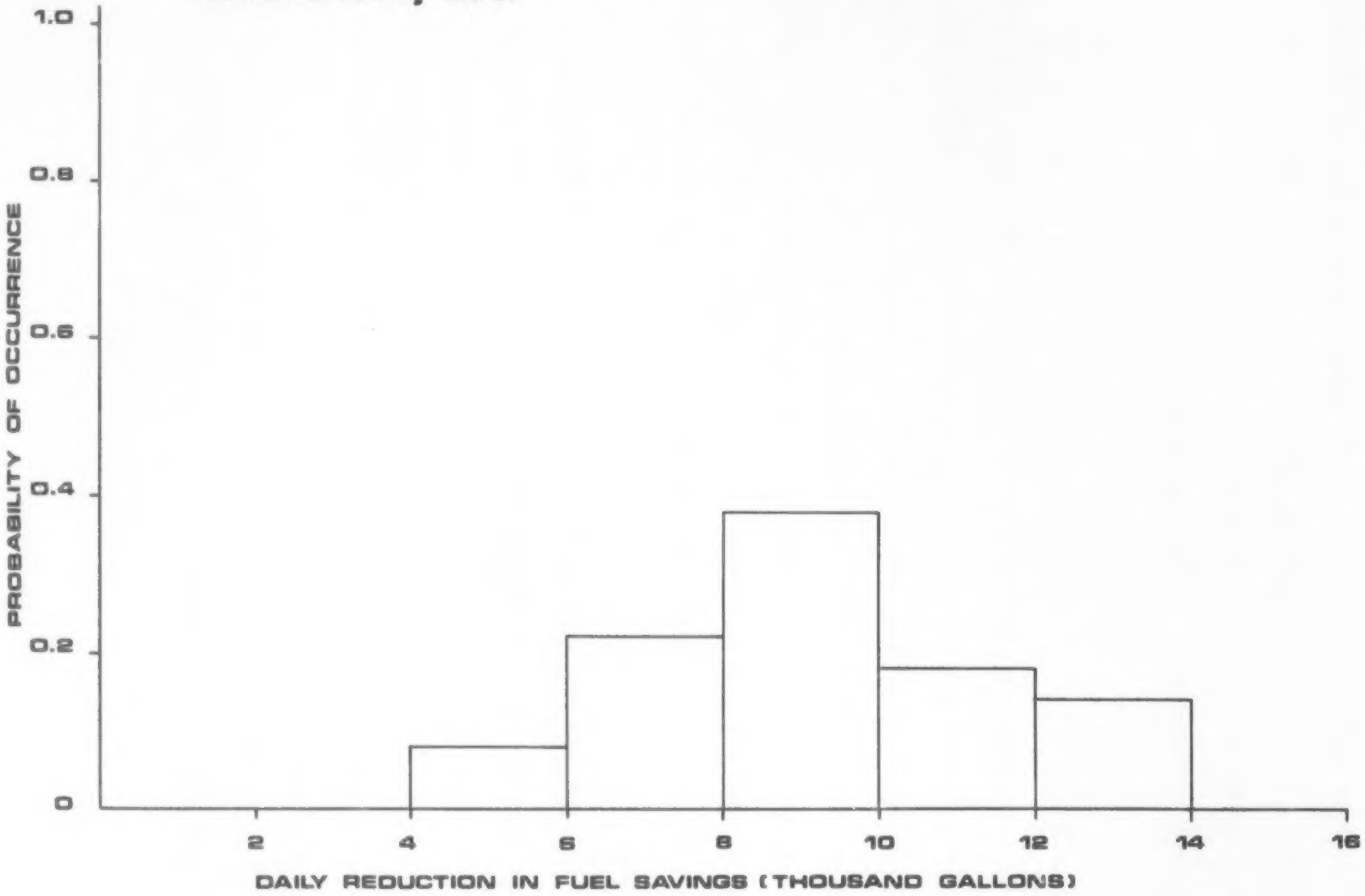
TABLE 3.4

WEEKDAY DISTRIBUTION OF PREVIOUS AUTOMOBILE DRIVERS

Time Period	Number	Percent
6-9 a.m.	4,990	23.0
9 a.m. - 3 p.m.	5,582	25.8
3-6 p.m.	7,506	34.7
Remainder of day	3,564	16.5
TOTAL	21,642	100

3.5

FUEL CONSUMPTION REDUCTION
ATLANTA, GA.



3.2.4 NET AIR POLLUTANT EMISSIONS REDUCTION

The expected distribution of CO emissions reduction is plotted in Figure 3.6 with an average reduction of approximately 13 tons per day. Hydrocarbon emissions would be reduced by 670 kilograms (kg) using 1975 average Environmental Protection Agency data.

3.3 WASHINGTON

Following a pattern similar to that already described for Atlanta, the Washington Metropolitan Area Transit Authority assumed regional bus service operations in mid-1972, and initiated a program of service expansion, public information, and equipment replacement. During 1974, bus miles of service in the Washington region were expanded by approximately 16 percent, reflecting a combination of increased service frequency on some lines, routing modifications, and the introduction of new lines primarily in outlying suburban areas.

Patronage response to these improvements has not been high--an increase of approximately five percent over the preceding year has been recorded[1]. This corresponds to a direct elasticity with respect to increased bus-miles of about 0.3, less than the 0.6 - 1.3 range estimated for Atlanta. As was noted in discussing Atlanta results, low ridership response is resulting in overall system load factor to be lowered.

No survey data exists regarding the prior mode or other characteristics of Washington's new transit riders, and consequently, information from the

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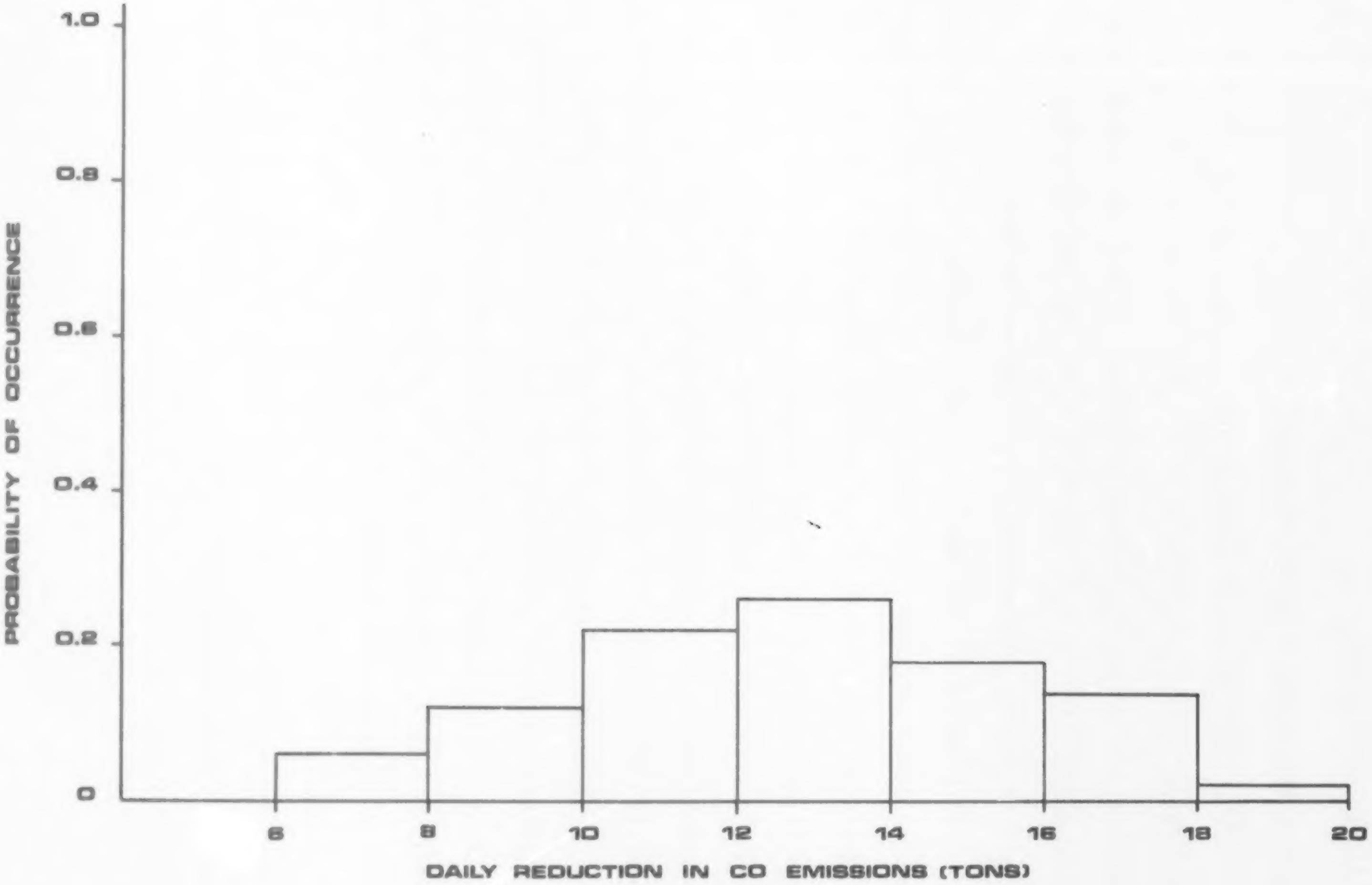
[1] Washington Metropolitan Area Transit Authority.

3.6

CO EMISSIONS REDUCTION
ATLANTA, GA.



Atlanta case study has been employed where required and additional parametric studies carried out.

3.3.1 NET ENERGY CONSUMPTION SAVINGS

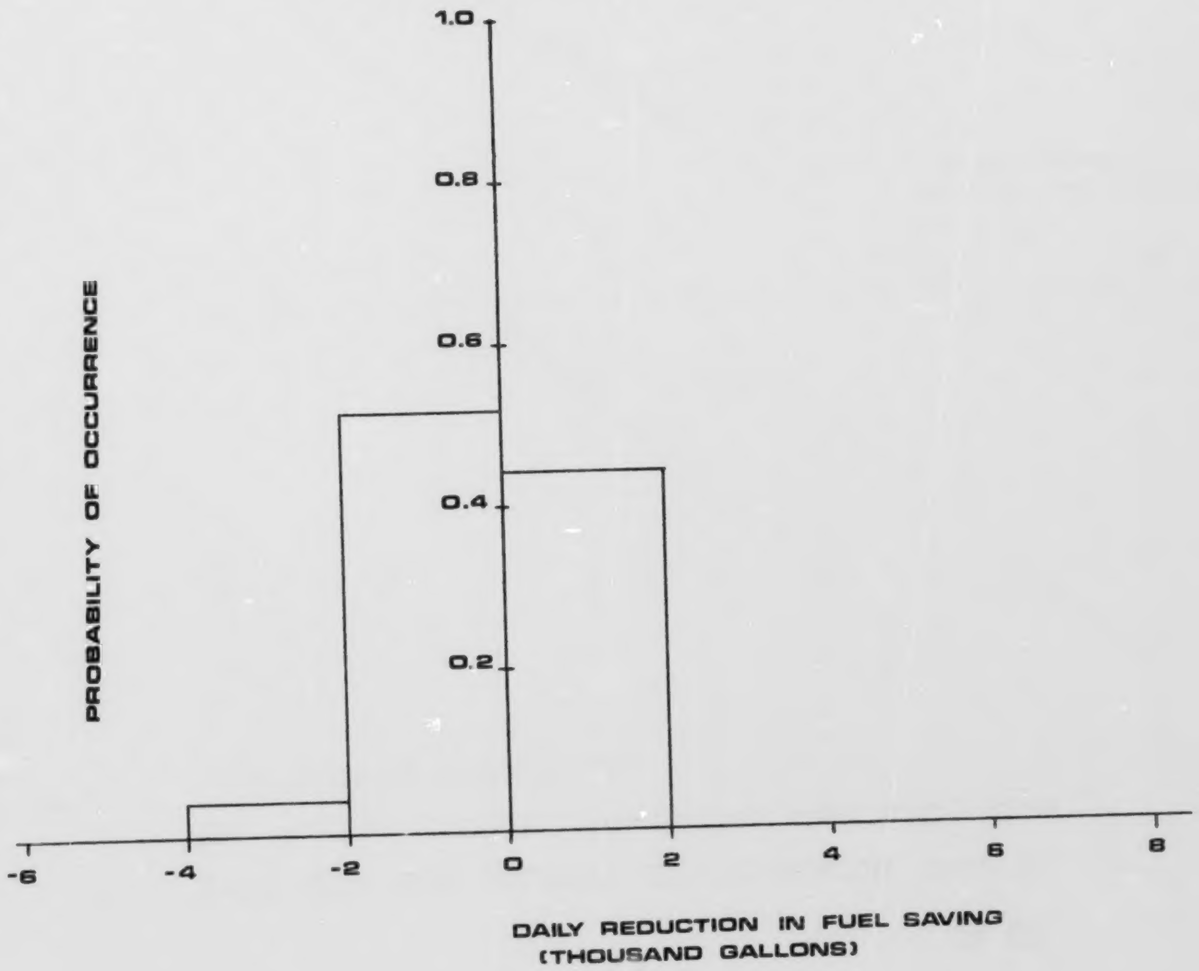
The distribution of expected fuel savings for Washington is illustrated in Figure 3.7 using Atlanta data to establish the mean of the function describing the number of diverted automobiles. Note that there is an estimated 0.56 probability of increased total fuel consumption in this case with an increase of 250 gallons expected per day on the average.

In Figure 3.8, the sensitivity of estimated daily fuel consumption changes to the number of auto trips diverted is illustrated. A breakeven point of 'zero' net fuel savings is reached when approximately 45-50 percent of new bus trips are diverted from automobile driving. With 75 percent auto diversion, average fuel savings of approximately 4,100 gallons per day would result assuming 1975 auto fleet and trip length characteristics. Furthermore, expected savings would be eliminated if either (a) the average trip length of diverted auto trips were approximately 4.6 miles or shorter, or (b) the diverted auto trips were made by automobiles averaging 24-25 miles per gallon in city driving conditions. Breakeven probability distributions for both auto trip length and average gasoline consumption are plotted in Figure 3.9.

If a 40 percent improvement in automobile gasoline consumption efficiency is assumed, expected net fuel savings have a higher probability of being negative. As shown in Figure 3.10, fuel consumption would increase unless more than approximately 70 percent of new bus riders have been diverted from auto driving.

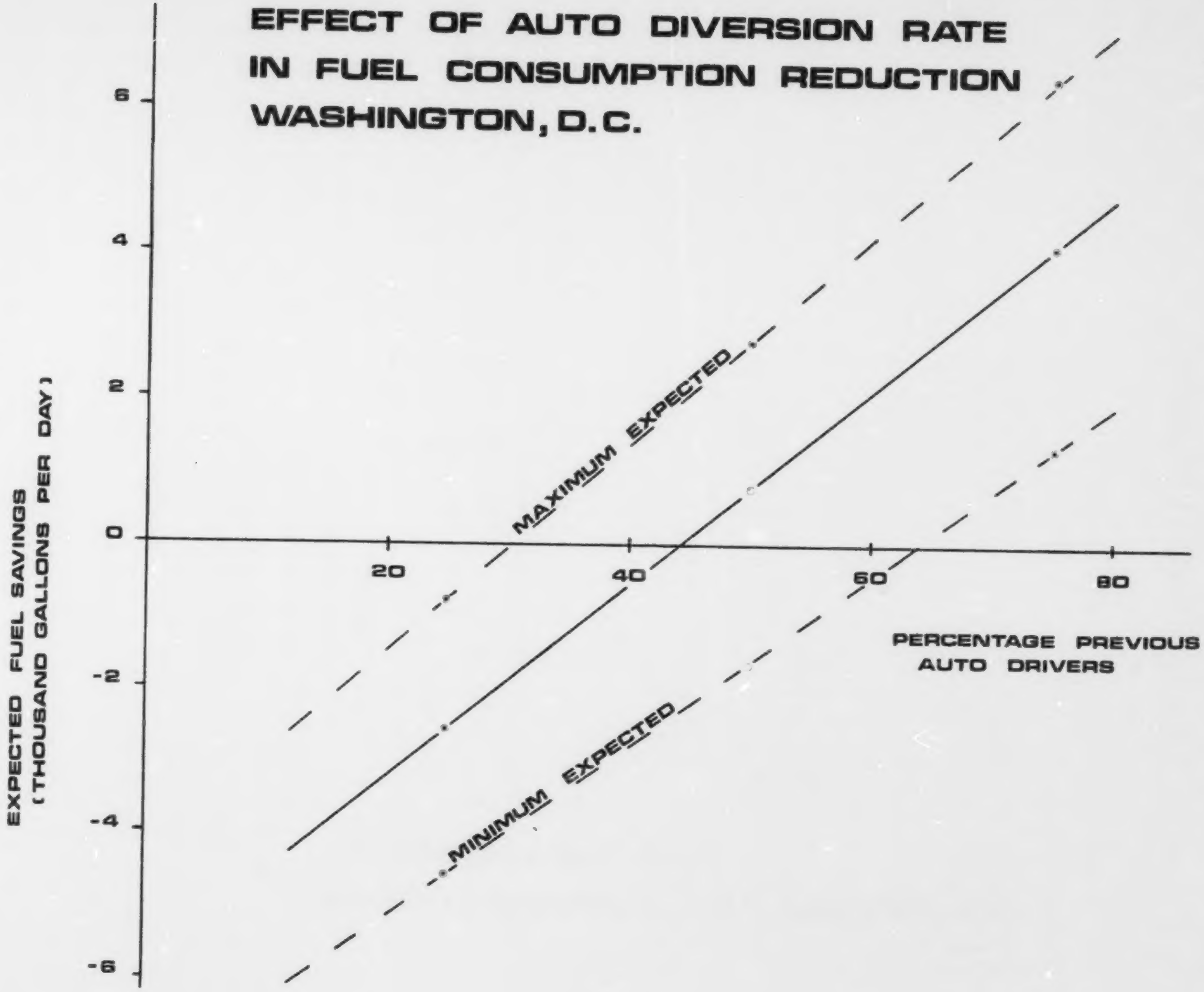
3.7

FUEL CONSUMPTION REDUCTION
WASHINGTON, D.C.



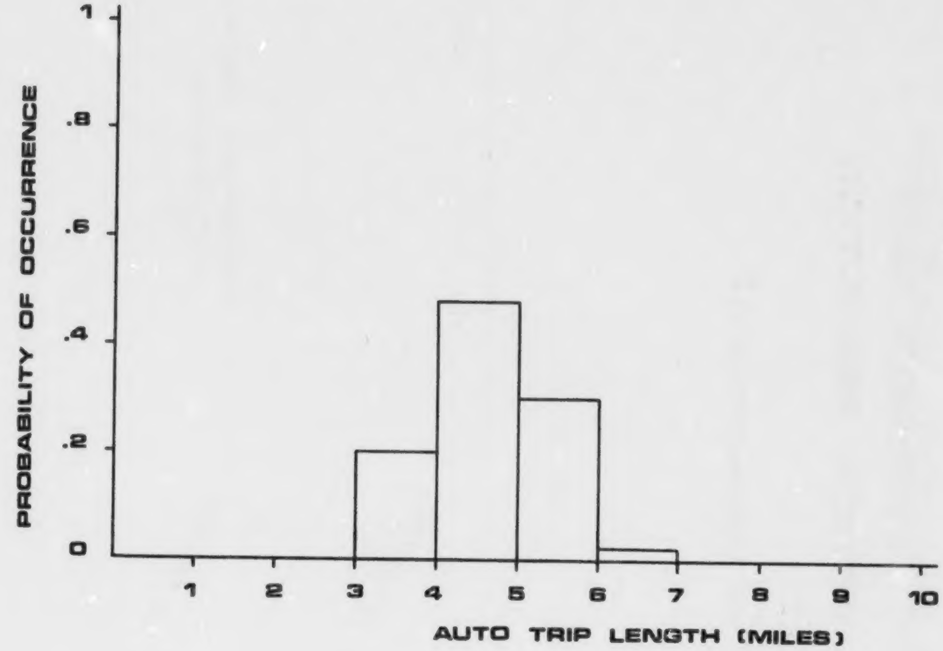
3.8

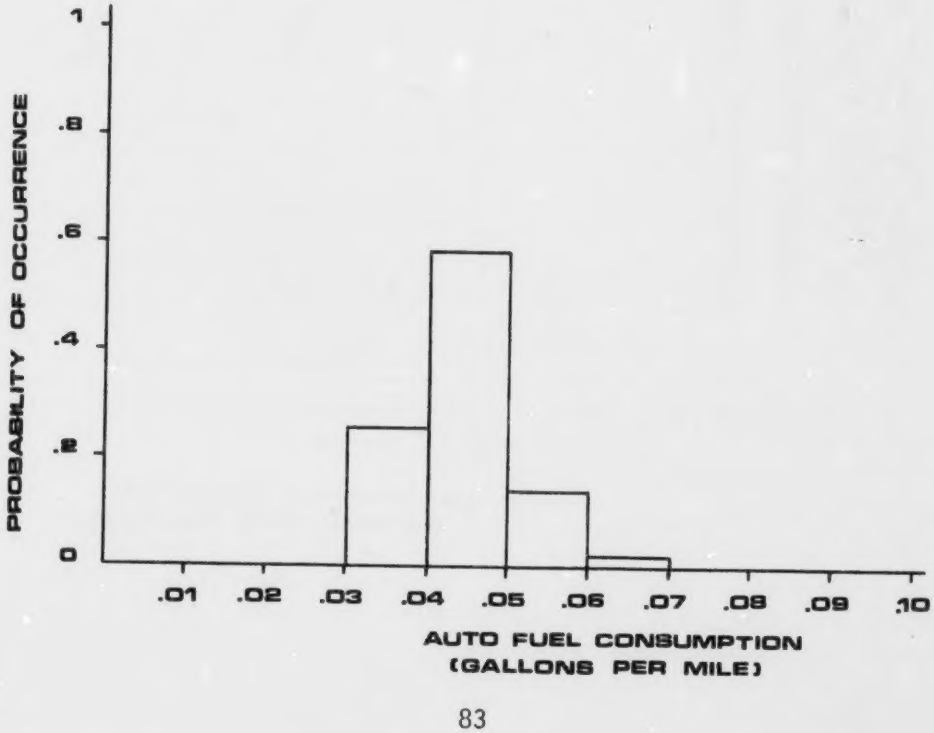
EFFECT OF AUTO DIVERSION RATE IN FUEL CONSUMPTION REDUCTION WASHINGTON, D.C.



3.9

BREAK-EVEN VALUES WASHINGTON, D.C.

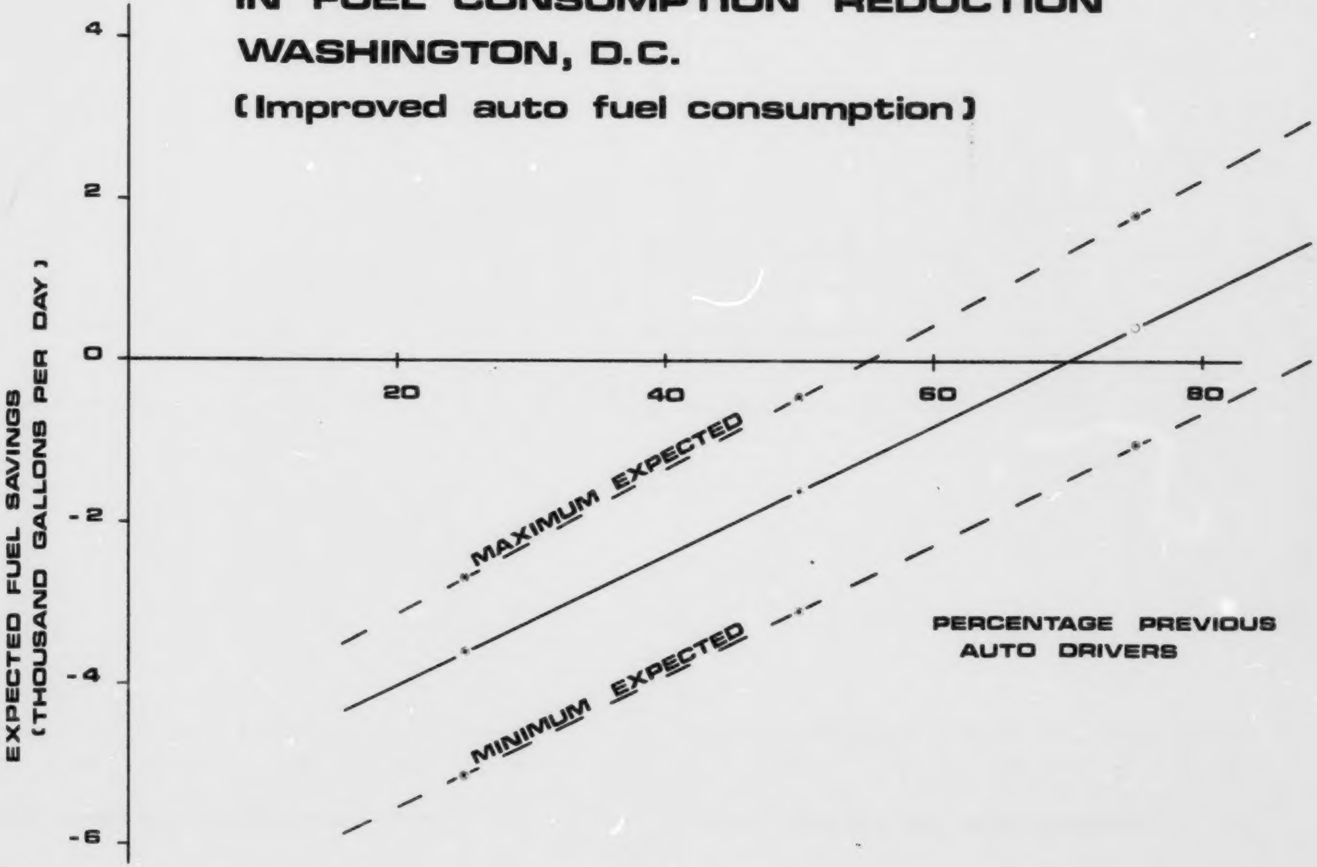




3.10

EFFECT OF AUTO DIVERSION RATE IN FUEL CONSUMPTION REDUCTION WASHINGTON, D.C.

(Improved auto fuel consumption)



3.3.2 NET AIR POLLUTANT EMISSIONS REDUCTION

Assuming 1975 auto fleet characteristics and data from Atlanta survey results, the improved Washington bus service program has generated CO emissions reductions as shown in Figure 3.11 with an average reduction of nearly six tons per day. The average reduction amount varies between an estimated three tons and 11 tons per day as the percentage of new transit riders assumed to be diverted from auto driving increases from 25 percent to 75 percent (see Figure 3.12). 1975 HC emissions would be reduced by approximately 260 kg, using Atlanta survey results regarding diverted auto characteristics.

In terms of requirements for meeting National Ambient Air Quality standards in the Washington region, the bus service improvements have made an effective contribution. Table 3.5 summarizes these requirements as specified in the Transportation Control Strategy which calls for a total CO emissions reduction of approximately 633 tons in the 6 a.m. to 2 p.m. period, including 21 tons attributed to implementation of transit and car pooling programs[1]. Assuming that one-half of the estimated CO emissions reduction due to expanded bus service may be credited to the maximum eight hour period, bus service improvements have contributed about fifteen percent of the required strategy amount. If an upper bound level corresponding to 75 percent auto diversion is assumed, the contribution amount is approximately doubled to nearly one-quarter of the strategy requirement.

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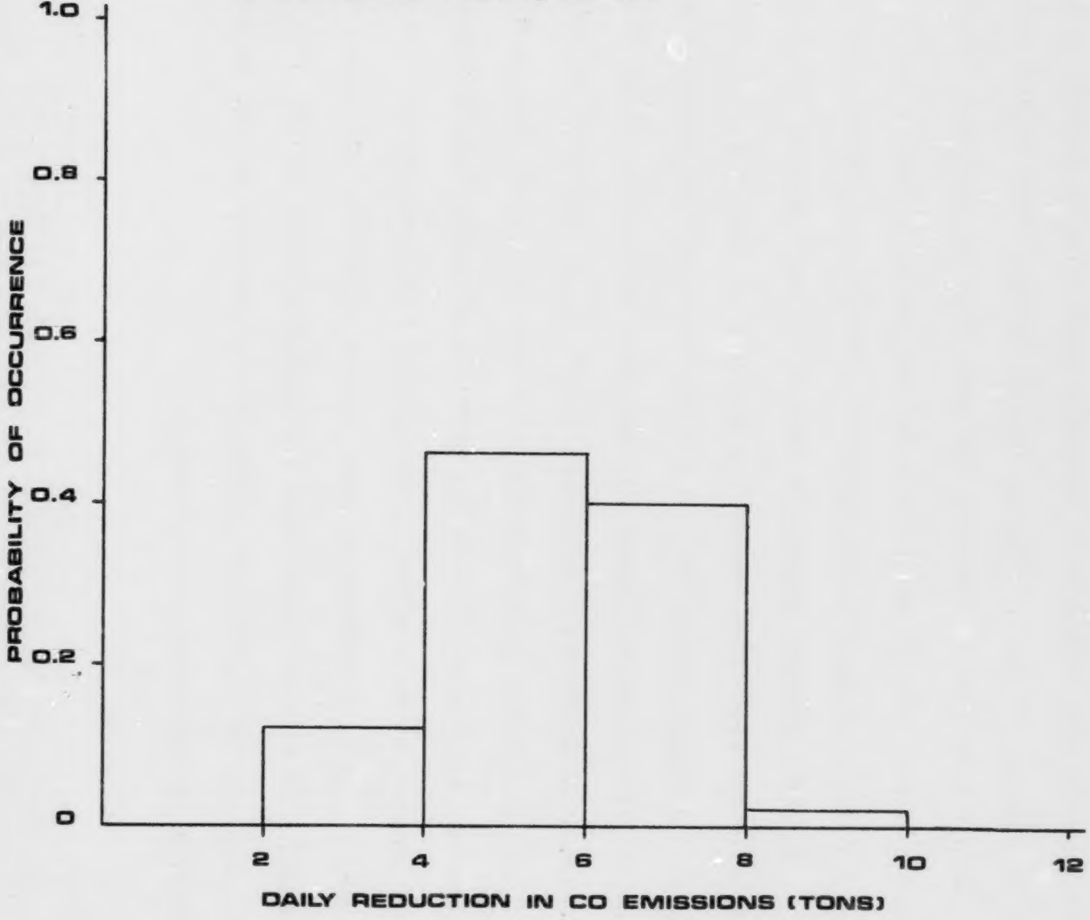
[1] District of Columbia Government, et al Additions and Revisions to the Implementation for the Control of Carbon Monoxide, Nitrogen Oxides, Hydrocarbons and Photochemical Oxidants for the District of Columbia Portion of the National Capital Interstate Air Quality Control Region, April, 1973.

3.11

REDUCTION IN CO EMISSIONS
WASHINGTON, D.C.



3.12

EFFECT OF AUTO DIVERSION RATE IN REDUCTION OF CO EMISSIONS WASHINGTON, D.C.

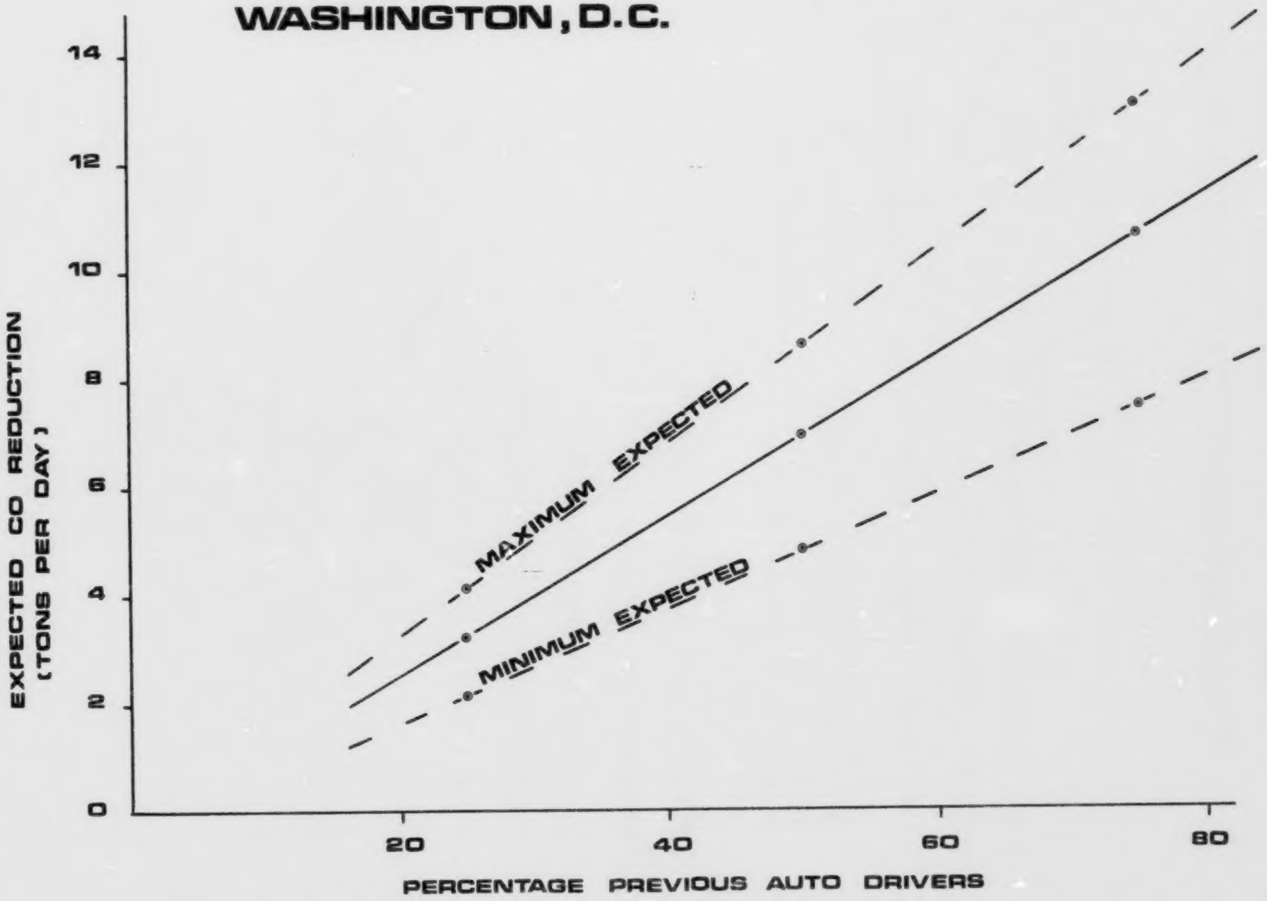


TABLE 3. 5

SUMMARY OF 1975 TRANSPORTATION CONTROL STRATEGY FOR WASHINGTON METROPOLITAN REGION

	6 a.m.-2 p.m. Tons	Percent of Total Reduction
Total CO Emission Reduction Required	633	100
Vehicle Turnover	343	54
Additional Reduction Required	290	
Transportation including improved mass transit, increased terminal costs, reciprocal enforcement of parking tickets, and car pool locator service	21	3
Vehicle Inspection and Maintenance	47	7
Retrofit of all pre-1975 Autos	177	28
Retrofit of all pre-1975 Light Duty Trucks	34	5
Selective Control of Goods Movement	56	9
Aircraft Taxiing Emission Reductions	30	5
TOTAL	708	112

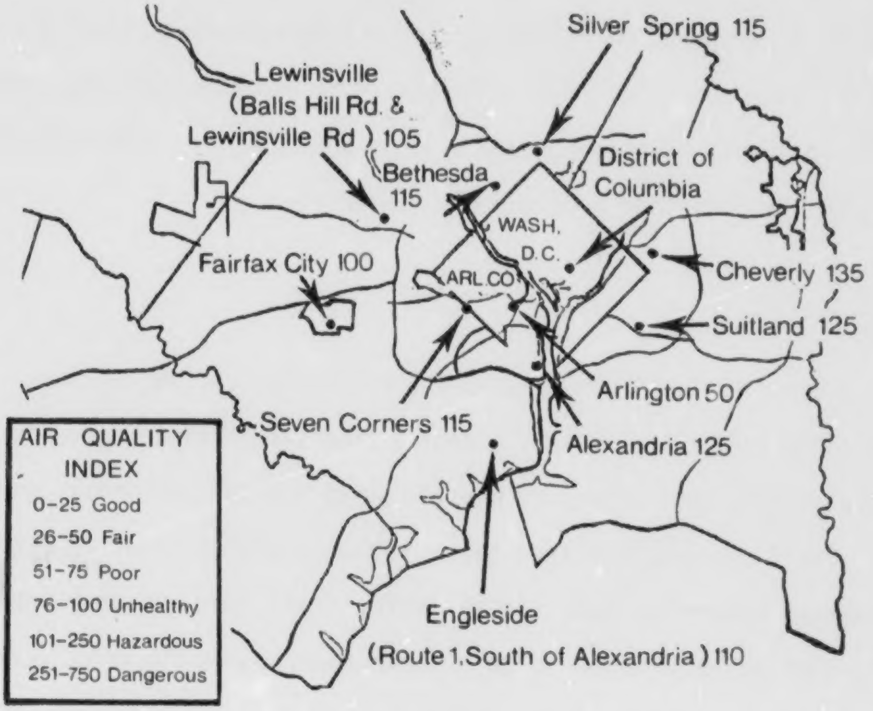
A second aspect of net air pollutant emissions reduction involves the geographic orientation of bus riding in the Washington area. Bus use patterns are highly oriented towards the central area of the region, and less intensive as the distance from the central area increases. This pattern is generally typical of many urban areas as well. Consequently, it may be considered that transit improvements will have relatively greater impact on air quality conditions in central portions of the region. For comparison, Figure 3.13 shows that Washington's air quality problems may be more pronounced in outlying suburban areas as was the case for the day shown during the summer of 1974. Even though transit may be effectively contributing towards attainment of air quality standards, it is not well suited to reduce auto usage outside of central area travel corridors where a large proportion of urban area travel and related air pollution problems may take place.

3.4 SAN DIEGO

In August 1972, the San Diego Transit Corporation lowered fares to a flat 25 cents (regardless of trip length) from the previous fare structure of a 40 cent base fare plus zone charges up to a total of ninety cents for a trip. The fare reduction resulted in a very sharp increase in patronage, and continued growth has been sustained since that time. Some of the more recent growth may be attributed to other factors including an extensive public information program by San Diego Transit.

3.13

AIR QUALITY INDEX READINGS
WASHINGTON, D.C.
JULY 1974


Silver Spring 115
Lewinsville
(Balls Hill Rd. &
Lewinsville Rd) 105
Bethesda
115
District of
Columbia
WASH.
D.C.
Fairfax City 100
ARL.CO.
Cheverly 135
Suitland 125
Arlington 50
Seven Corners 115
Alexandria 125
Engleside
(Route 1,South of Alexandria) 110
AIR QUALITY
INDEX
0-25 Good
26-50 Fair
51-75 Poor
76-100 Unhealthy
101-250 Hazardous
251-750 Dangerous

Note: The air quality index is a
composite measure of several
air pollutant concentrations

A second major service change in the region has involved implementation of the fiscal year 1975 action plan. This plan was envisioned to add some 63 percent more bus miles of service. As of February, 1975, implementation of the action plan has been frozen, with slightly more than half of the incremental route miles in service. The freeze was the result of a combination of factors including sharply increased operating costs, the lack of sufficient buses to implement the complete program, increased maintenance requirements on the buses because of heavier loads and greater usage, and the disappointing patronage on many of the action plan routes already implemented. It is uncertain when the remaining routes will be implemented.

For this study, introduction of the fuel action plan has been assumed to provide a second San Diego case study. Ridership estimates derived for this case have been used for study analyses reported in a subsequent section[1].

3.4.1 NEW RIDERSHIP

The 1972 fare reduction program resulted in average passenger fares dropping from 28 cents to 23 cents, a change of approximately 39 percent. Applying empirical relationships, ridership would be expected to increase by 6-13 percent in response to lower fares. However, coupled with a 29 percent increase in bus-miles operated, a dramatic increase of 16 percent was recorded over a two-year period. From this data, an elasticity with respect to increased bus-miles of between 1.7 and 1.9 may be inferred--approximately double the average value computed for Atlanta and six times that estimated for Washington, D. C. areawide bus service improvements.

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[1] De Leuw, Cather & Company. "Preliminary Evaluation of Existing Transit Operations," Working Paper No. 1. Prepared for the Comprehensive Planning Organization of the San Diego Region, April, 1974.

The 1975 action plan involved expansion of bus-miles of service by 63 percent, with ridership projected to increase by 26 percent. In this case, direct ridership elasticity with respect to bus-miles is approximately 0.4, resulting in a lower system load factor following implementation of service improvements.

No survey information was available for either case study. Data inputs regarding the mode shift characteristics of new riders for the Atlanta case study have been utilized for modeling analyses.

3.4.2 NET ENERGY CONSUMPTION SAVINGS

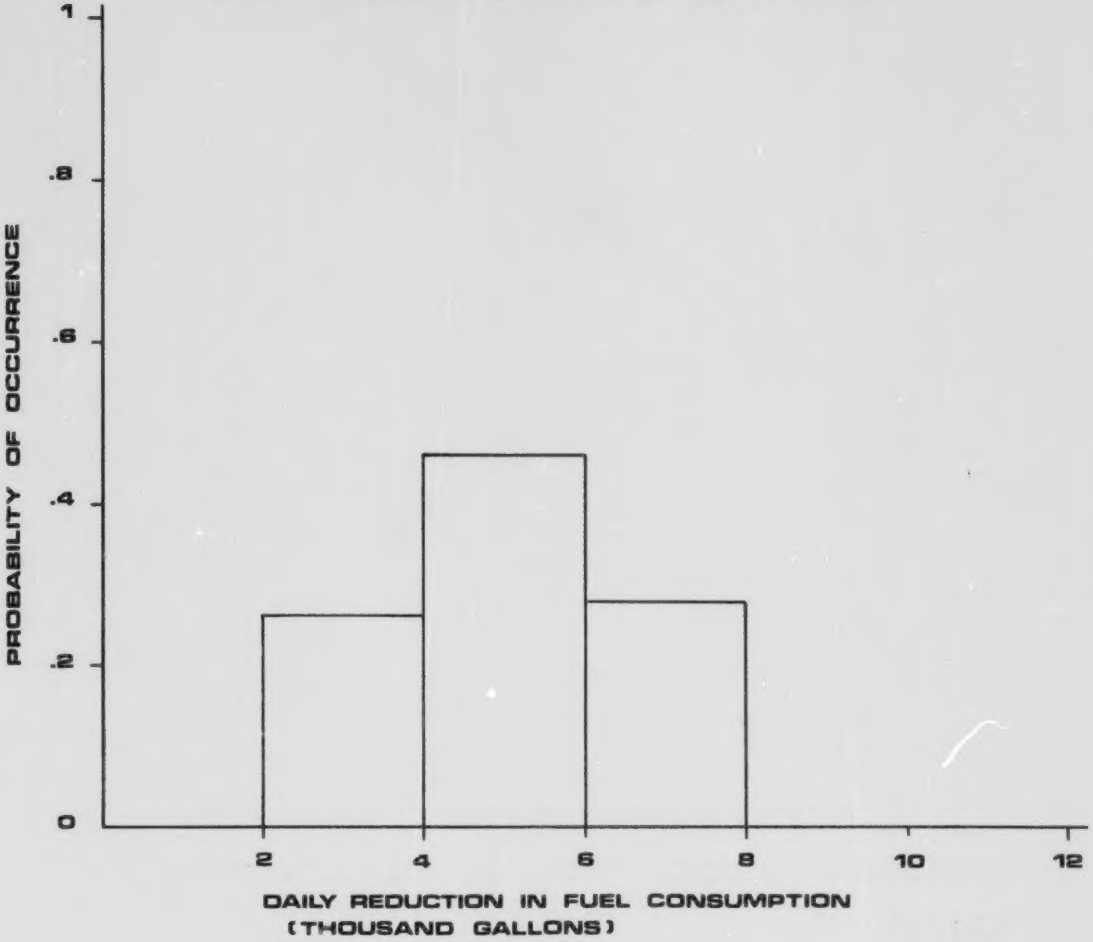
Figure 3.14 shows the net fuel savings probability distribution function associated with the 1972 fare reduction and service expansion program. The average savings of nearly 5,000 gallons per day represents less than one percent of daily 1975 passenger transportation energy utilization in the San Diego region. Figure 3.15 summarizes the results of varying diverted auto trip lengths on net fuel savings. The bounded area encompasses 99-percentile output values generated by sampling at random from input variable distributions for diverted auto trip characteristics. Fuel savings results except when average diverted auto trip lengths are less than approximately two miles.

Assuming that average auto fuel consumption efficiency is improved by forty percent, expected fuel savings remain positive with an average of about 2,300 gallons per day as shown in Figure 3.16.

As would be expected, estimated fuel savings due to the 1975 action plan improvements which involve an increase of twice as many new bus-miles

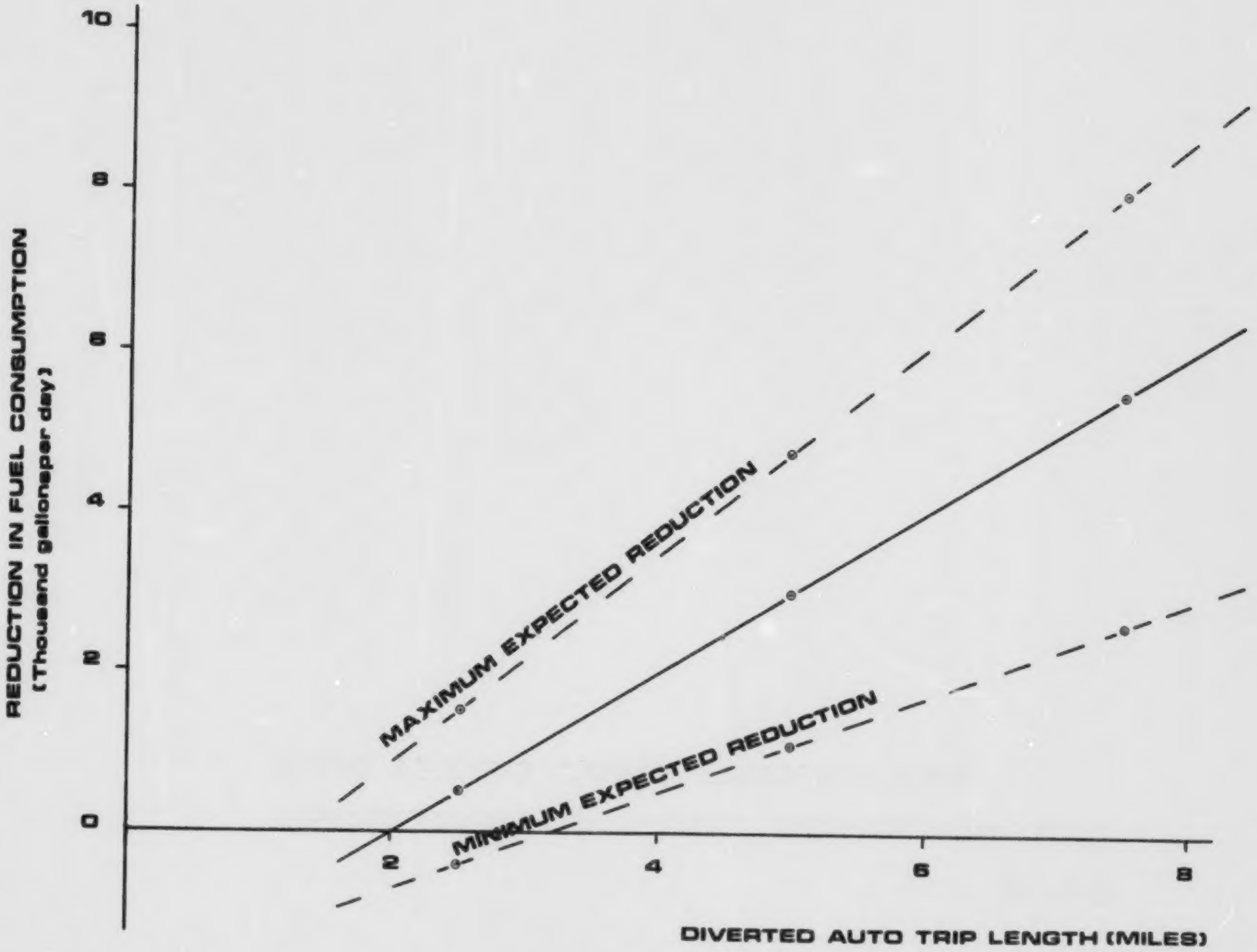
3.14

REDUCTION IN FUEL CONSUMPTION SAN DIEGO FARE REDUCTION



3.15

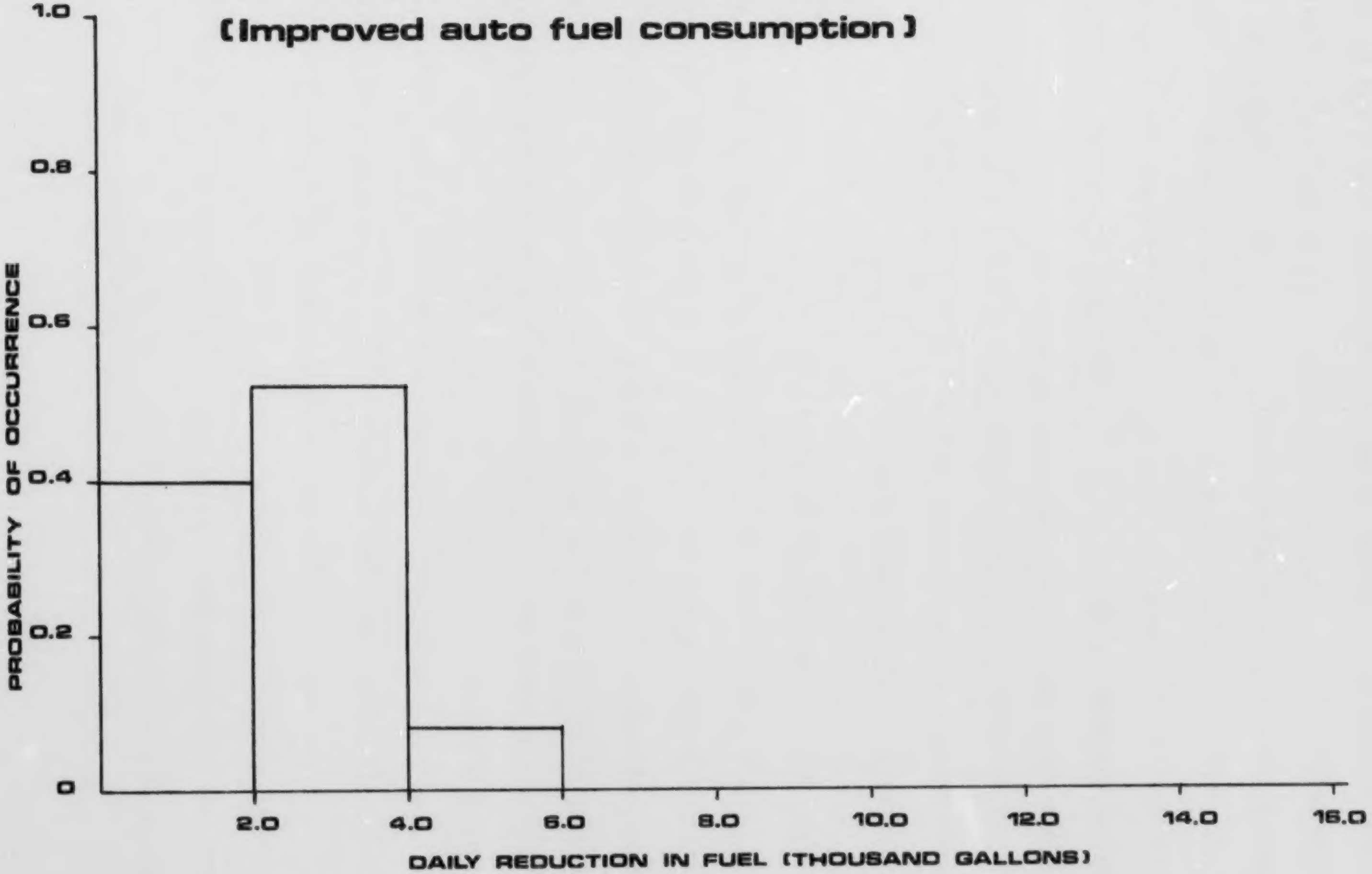
REDUCTION IN FUEL CONSUMPTION SAN DIEGO FARE REDUCTION



3.16

REDUCTION IN FUEL CONSUMPTION SAN DIEGO FARE REDUCTION

(Improved auto fuel consumption)



of service and lower patronage response than for the fare reduction program would be smaller. Average energy consumption would be slightly reduced with 0.44 probability of increased consumption (see Figure 3.17). Expected fuel savings over a range of diverted auto trip lengths are summarized in Figure 3.18, indicating actual energy use increases when average trip lengths are less than eight miles. No data is available regarding the trip length characteristics of new bus riders in the San Diego region, although average trip lengths are probably less than eight miles.

If average auto gasoline efficiency is improved by 40 percent, increased fuel consumption results with high probability for expected diverted auto trip characteristics (see Figure 3.19).

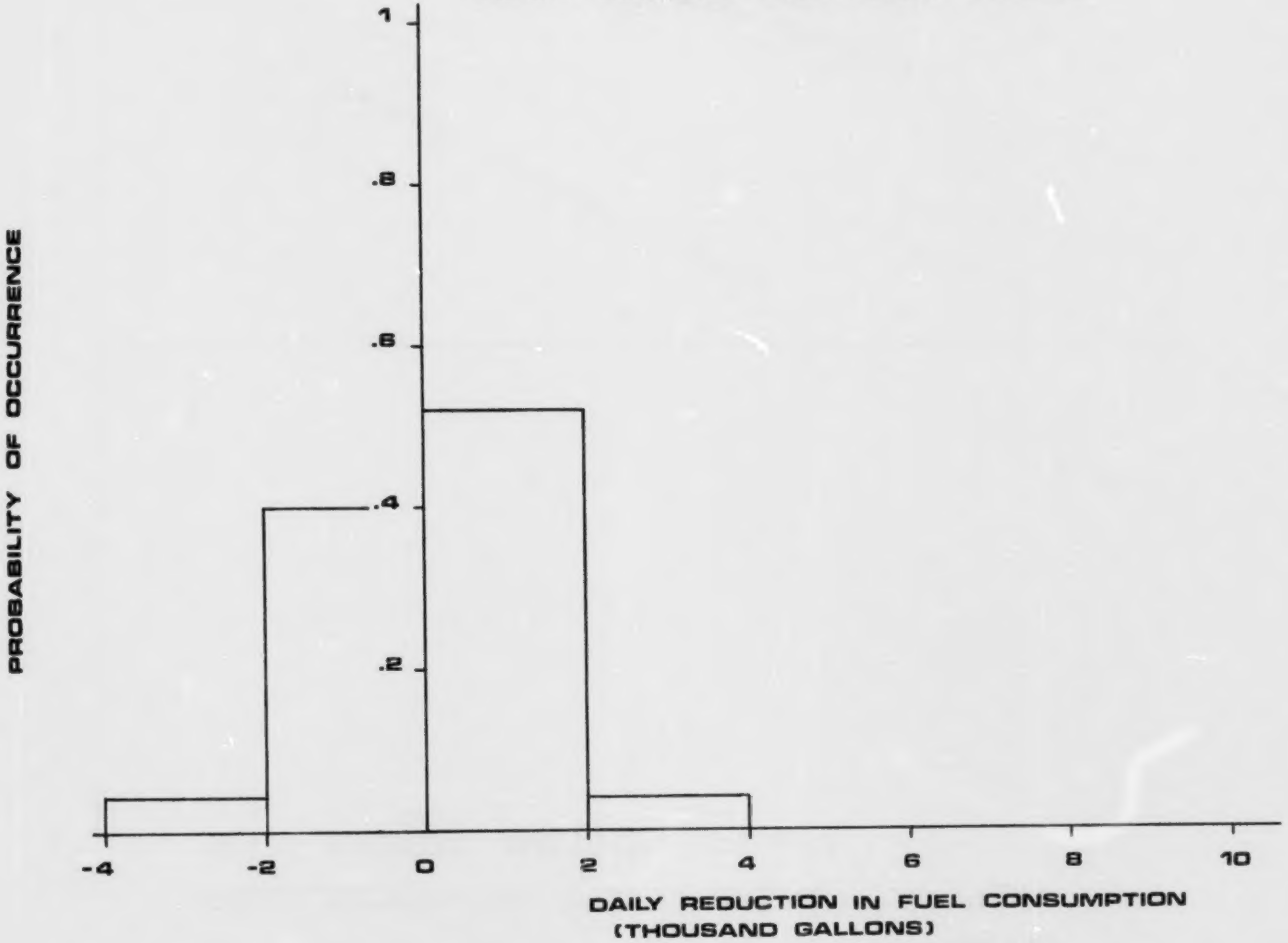
3.4.3 NET AIR POLLUTANT EMISSIONS REDUCTION

The San Diego fare reduction program would lower CO emissions by approximately 7.5 tons per day and HC emissions by 400 kg per day for 1975 auto fleet characteristics. The CO emissions reduction probability distribution function is plotted in Figure 3.20 In Figure 3.21 the range of CO emissions reductions is shown for varying diverted auto trip lengths including 99-percentile minimum and maximum values.

For the 1975 action plan improvement package, the net CO emissions reduction distribution function is shown in Figure 3.22 with a mean reduction of 5.4 tons per day. The expected reduction level varies according to the average length of diverted auto trips as plotted in Figure 3.23. For 1975 national auto fleet characteristics, an average net HC reduction of approximately 240 kg has been estimated.

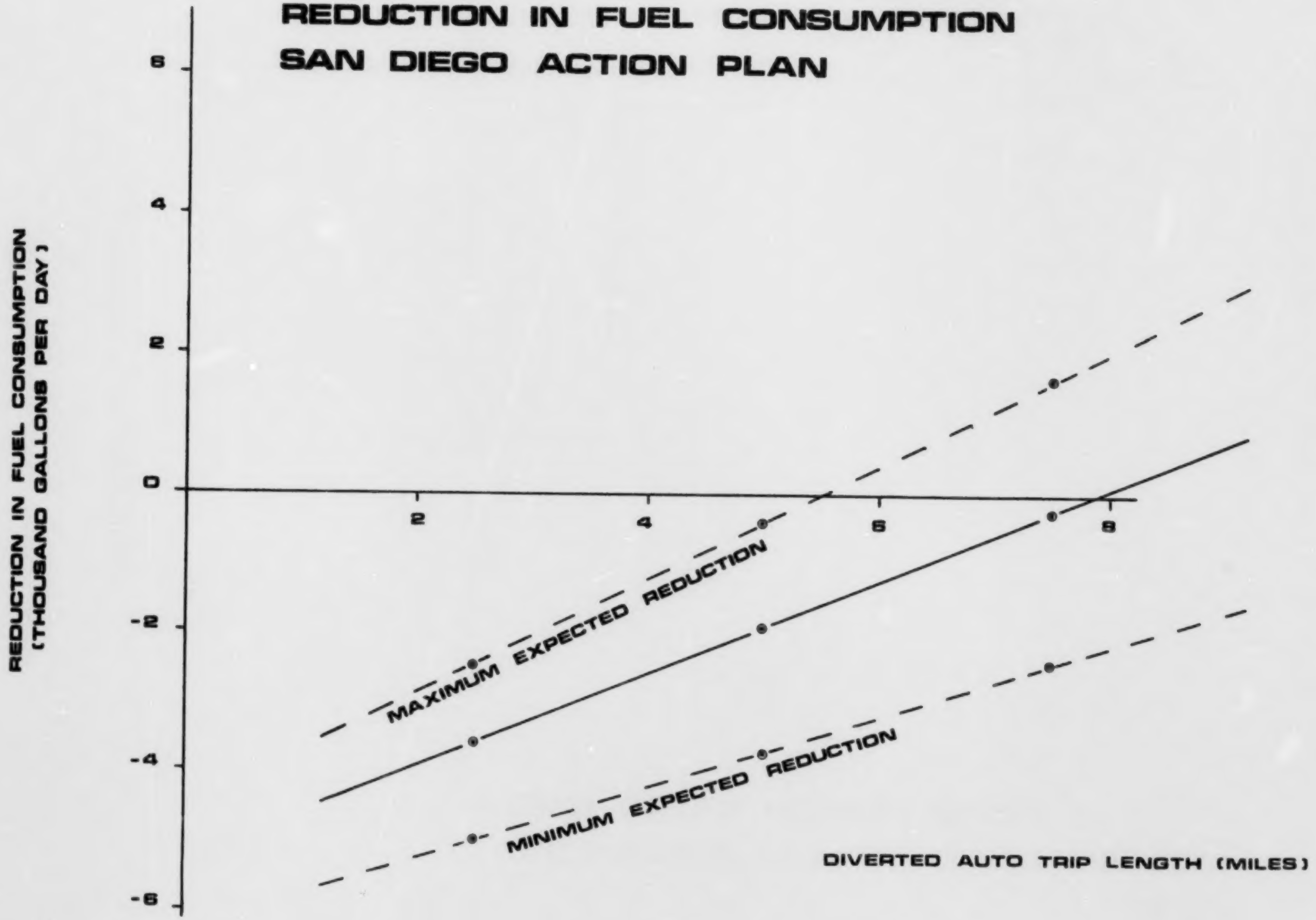
3.17

REDUCTION IN FUEL CONSUMPTION
SAN DIEGO ACTION PLAN



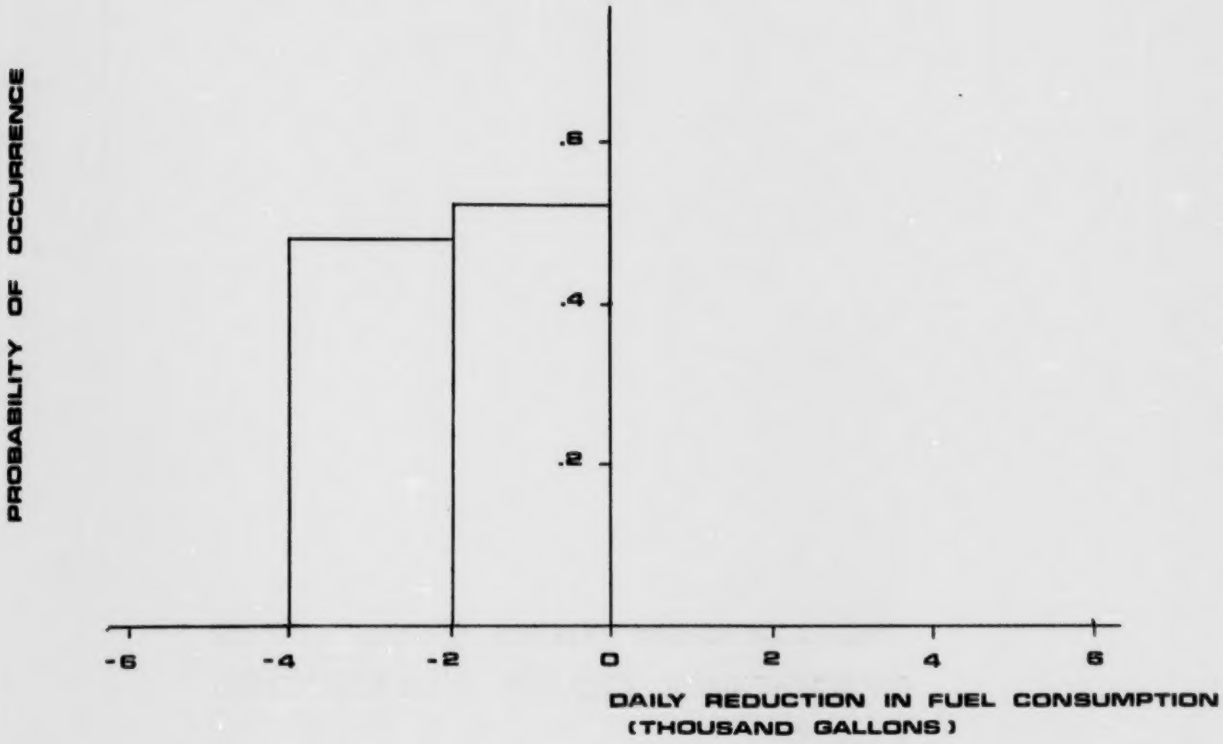
3.18

REDUCTION IN FUEL CONSUMPTION SAN DIEGO ACTION PLAN



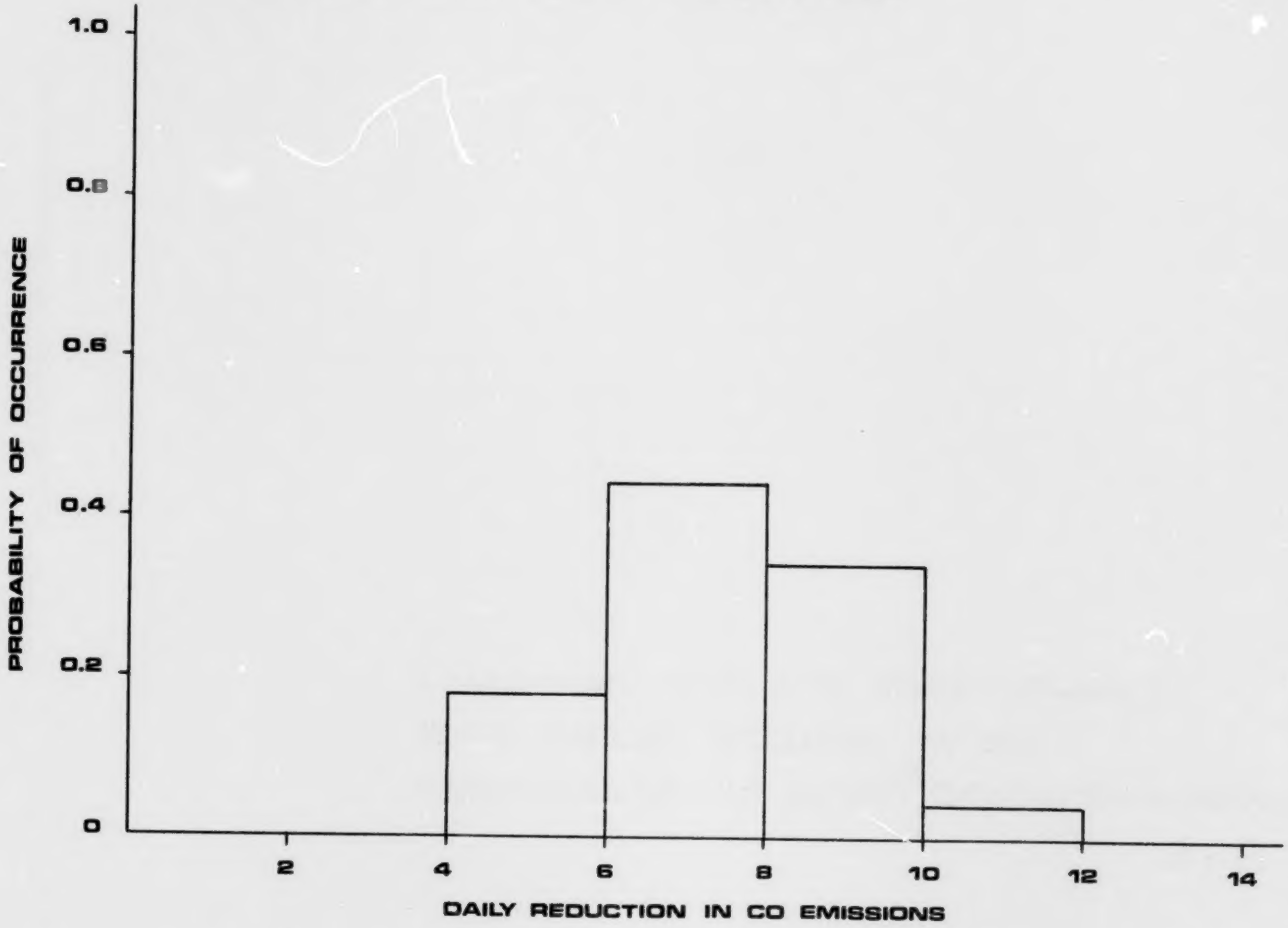
3.19

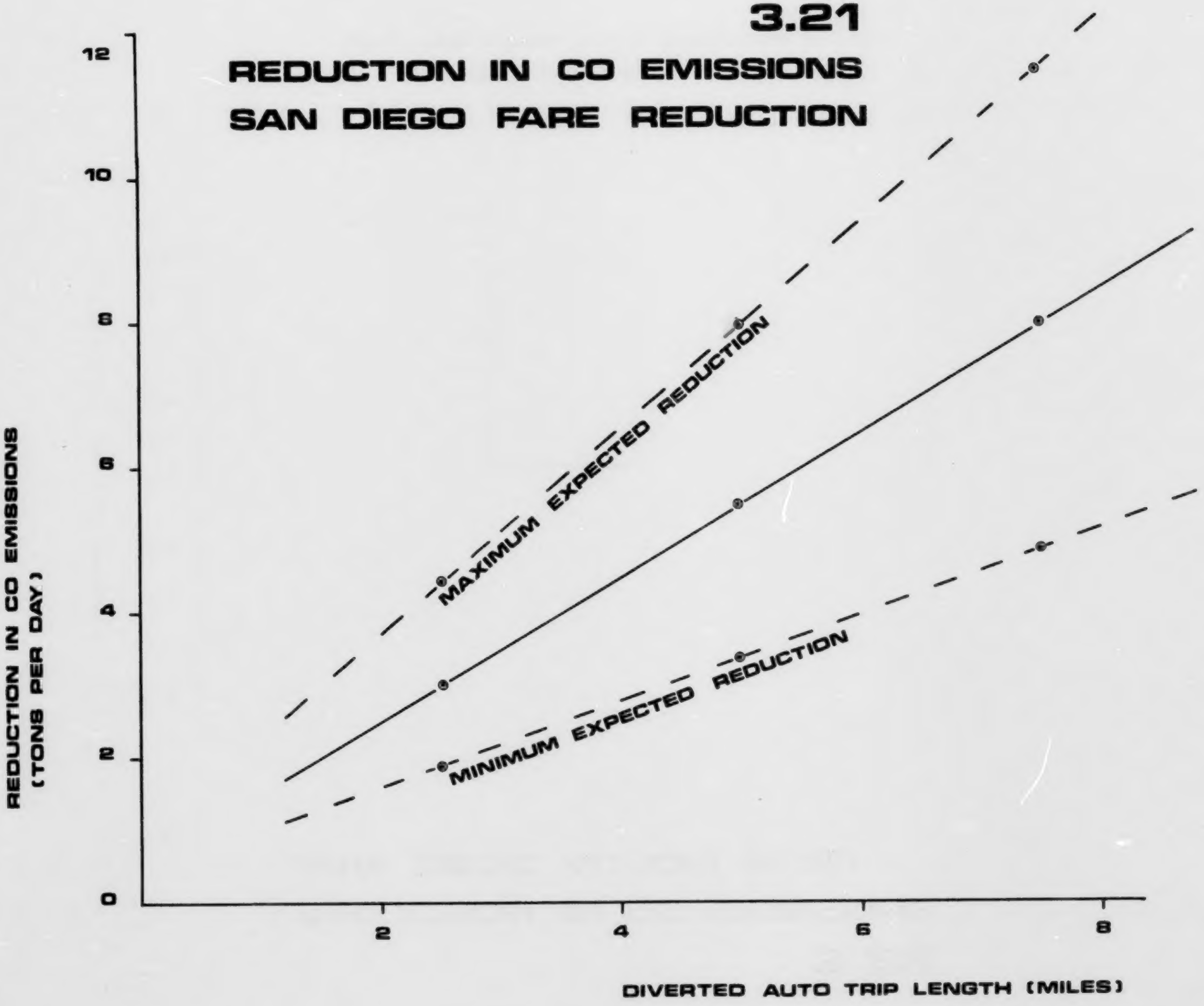
REDUCTION IN FUEL CONSUMPTION
SAN DIEGO ACTION PLAN
(Improved auto fuel consumption)



3.20

REDUCTION IN CO EMISSIONS
SAN DIEGO FARE REDUCTION



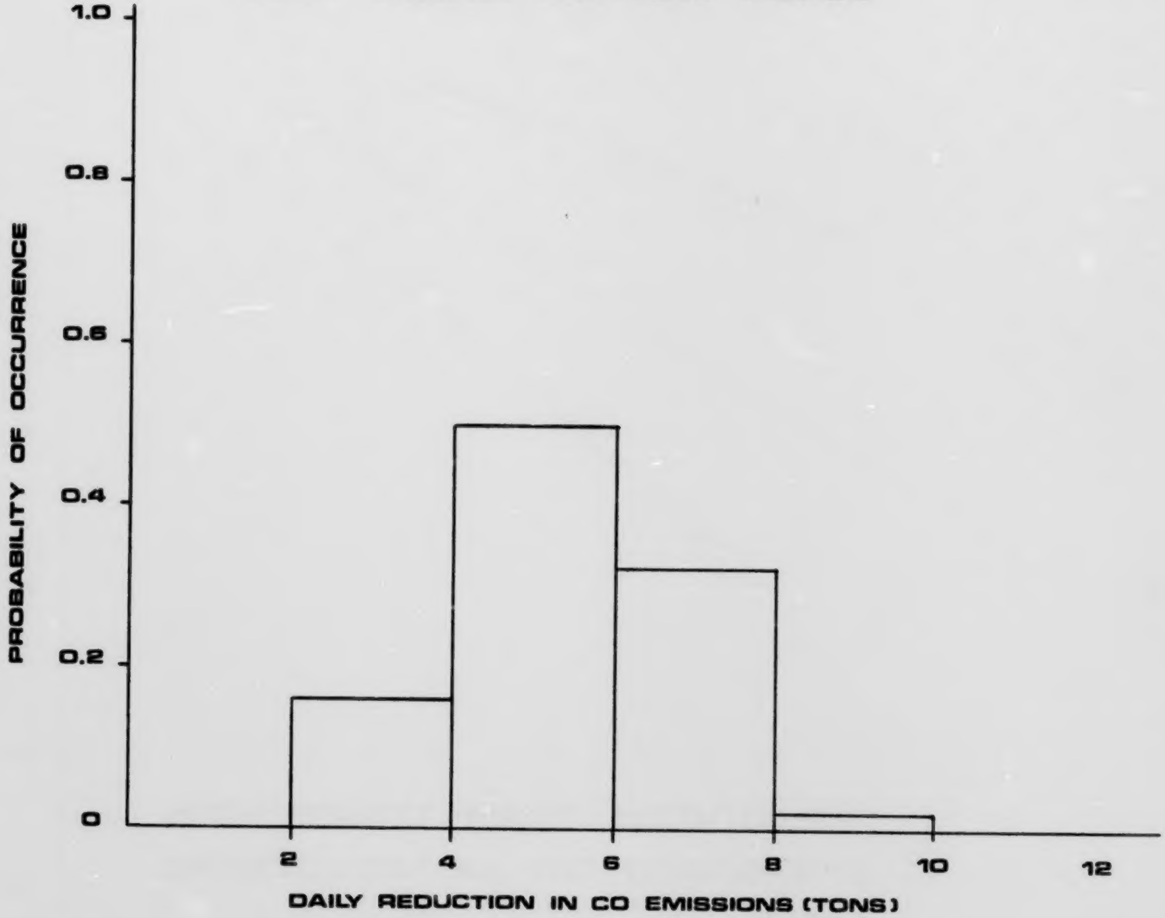


3.21

REDUCTION IN CO EMISSIONS
SAN DIEGO FARE REDUCTION

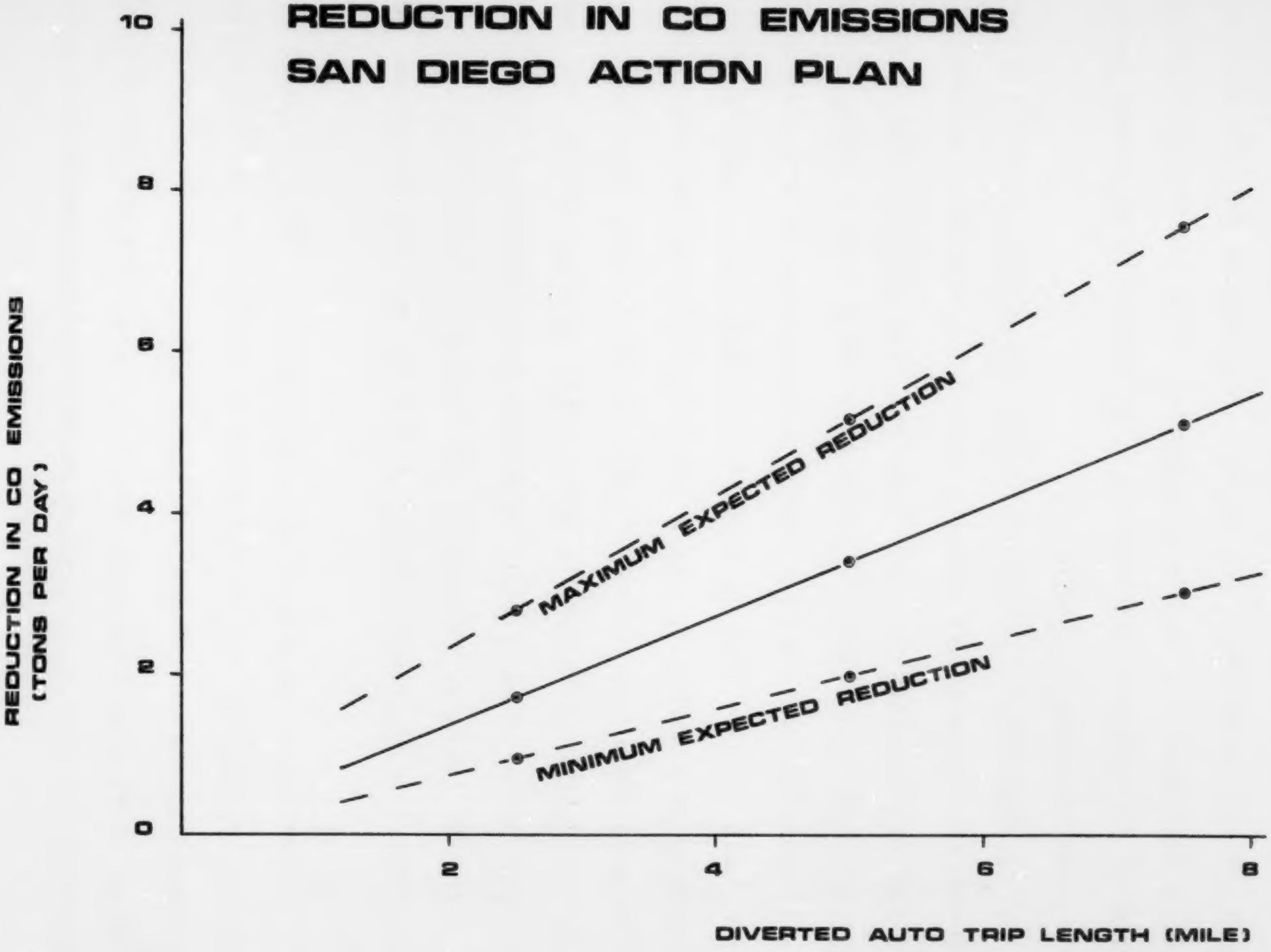
3.22

REDUCTION IN CO EMISSIONS
SAN DIEGO ACTION PLAN



3.23

REDUCTION IN CO EMISSIONS SAN DIEGO ACTION PLAN



3.5 ORANGE COUNTY

Located in suburban Los Angeles, Orange County is the fastest growing metropolitan area in the State of California with a population of approximately 1.8 million persons. The county is characterized by low density suburban development, served by an extensive street and freeway network, typical of its Southern California location as well as many other large urban areas throughout the country.

To compete with the automobile in this environment of diffused travel patterns, the Orange County Transit District has undertaken implementation of a public transportation system comprised of a number of community or local area bus systems which serve intra-community travel needs, while simultaneously serving as collection and distribution subsystems for an extensive county-wide network of bus routes designed to facilitate inter-community travel. In February 1973, community demand responsive (dial-a-ride) service was initiated in LaHabra as a pilot project. At the present time, seven additional communities are receiving local demand actuated service, and county-wide fixed route, fixed schedule service is being operated. Neither system is considered complete, and systems are growing in ridership as service is being offered in increasing amounts where practically no service was offered before.

The results of the Orange County program are of national interest and potential application. As was mentioned in interpreting the Washington findings regarding the central area corridor orientation of conventional transit services, urban areas throughout the country are addressing the question of penetrating the automobile market in suburban areas. The approach under development in Orange County offers a potential means for providing a transportation alternative.

3.5.1 NEW RIDERSHIP

The Orange County Transit District operates 524,000 miles of bus service monthly, providing at least one hour service in selected communities. At the present time, average weekday ridership is about 24,000 riders, equivalent to only 0.5 percent of the 4.5 million daily trips made by county residents.

3.5.2 NET ENERGY CONSUMPTION SAVINGS

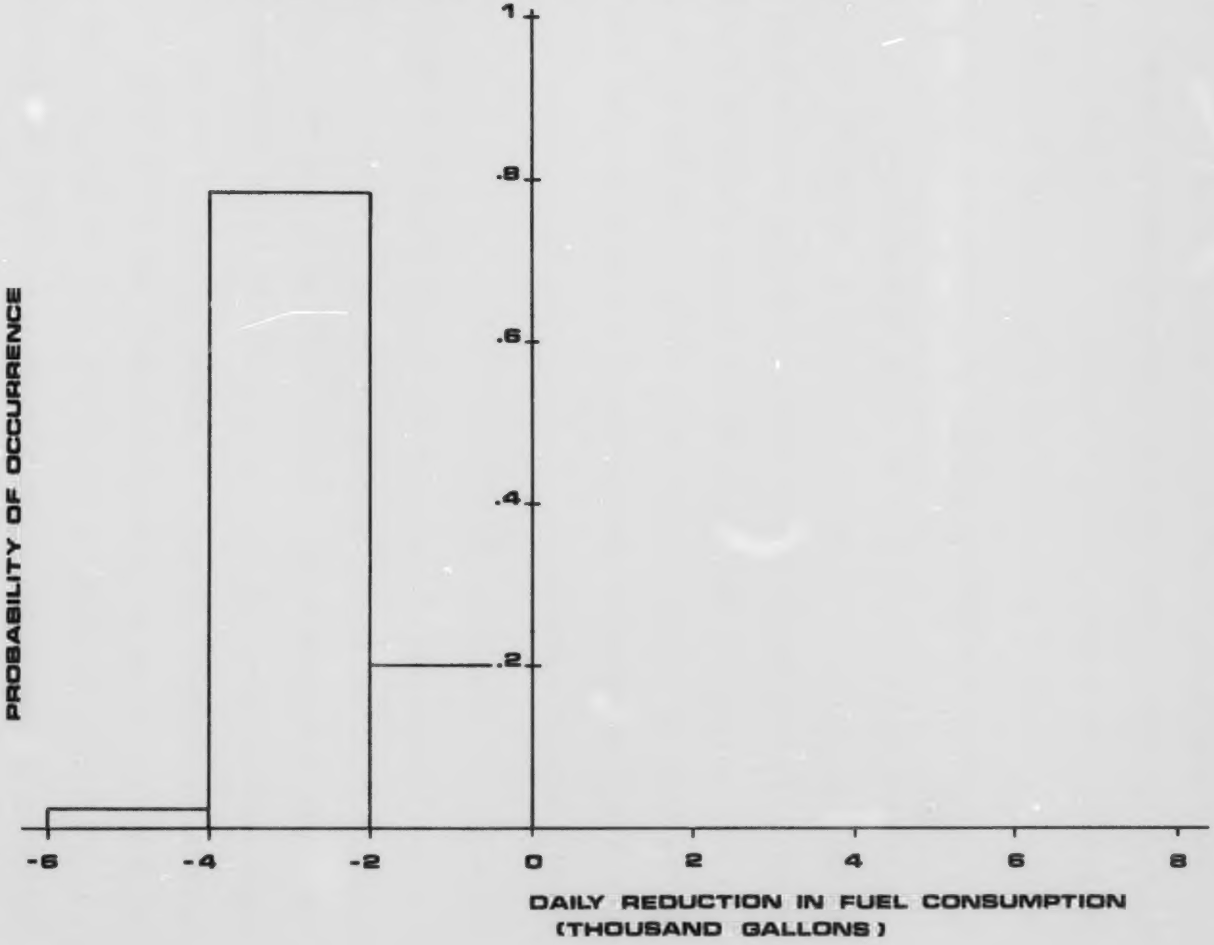
Figures 3.24 and 3.25 show the estimated probability distributions for net fuel consumption increases resulting from Orange County bus service introduction, assuming that 25 percent and 50 percent of new riders are diverted from auto driving. In both cases, five miles was assumed as the modal value for the diverted auto trip length input function. In Figure 3.26 average net fuel savings are shown for combinations of number of diverted auto trips and diverted auto trip length.

3.5.3 NET AIR POLLUTANT EMISSIONS REDUCTION

The introduction of county bus service has resulted in lower 1975 air pollutant emissions levels dependent on the degree of auto diversion and the length of diverted trips. Average net CO emissions reductions are summarized in Figure 3.27 for a range of diverted trip characteristics. For example, an estimated reduction of between 1.0 and 3.4 tons per day results if 25 percent of new bus trips were formerly auto driver trips ranging from 2.5 to 7.5 miles in length on the average. For the same diverted trip characteristics, between 20 and 130 kg of HC emissions would also be eliminated.

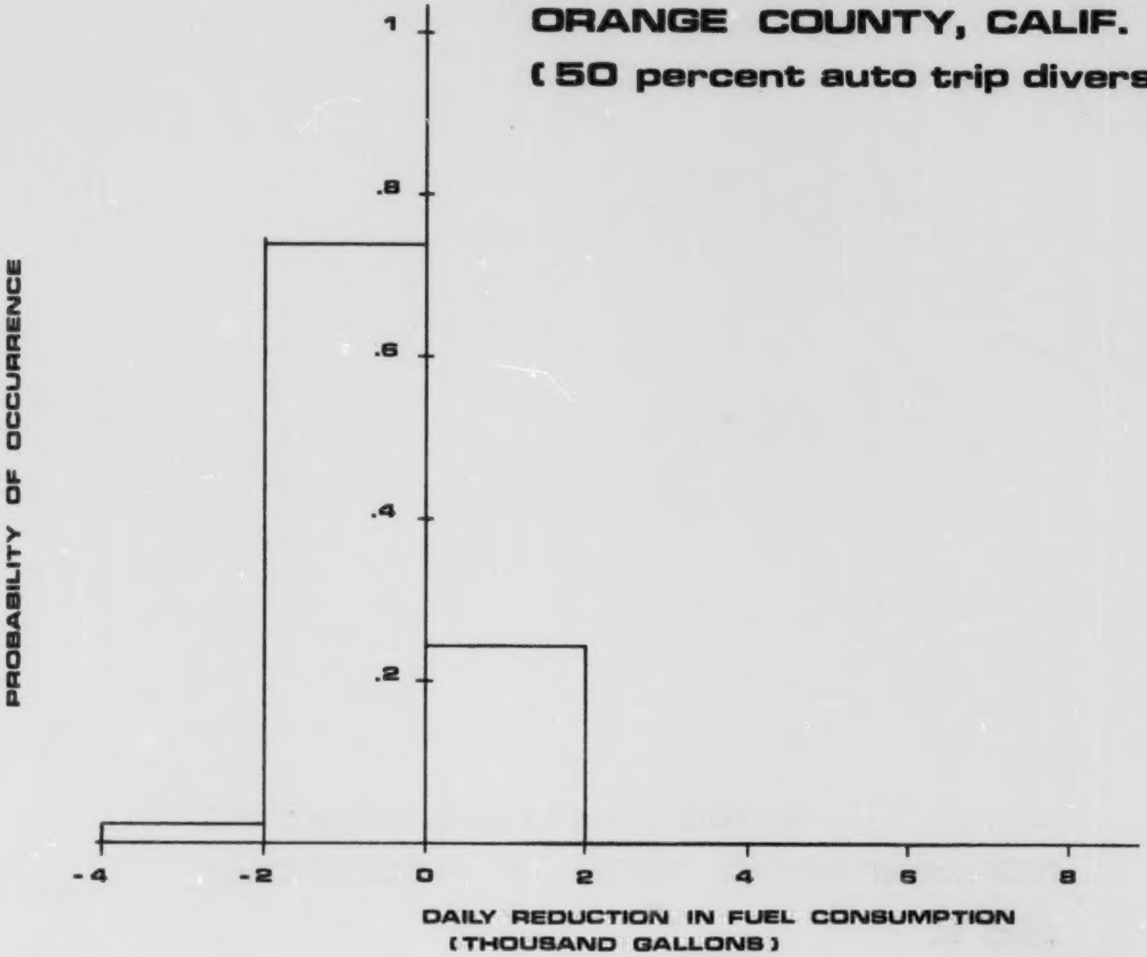
3.24

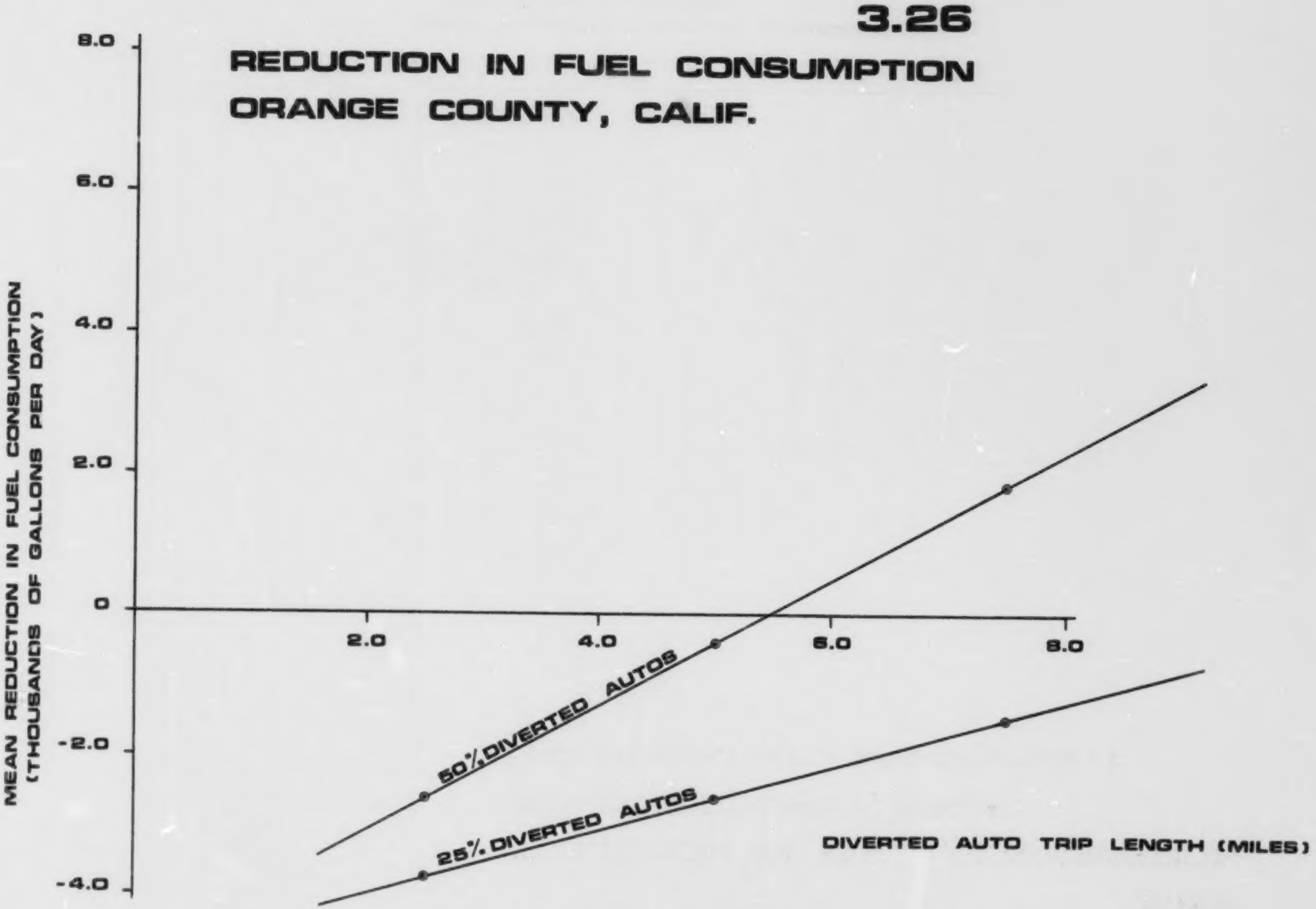
REDUCTION IN FUEL CONSUMPTION
ORANGE COUNTY, CALIF.
(25 percent auto trip diversion)



3.25

REDUCTION IN FUEL CONSUMPTION
ORANGE COUNTY, CALIF.
(50 percent auto trip diversion)



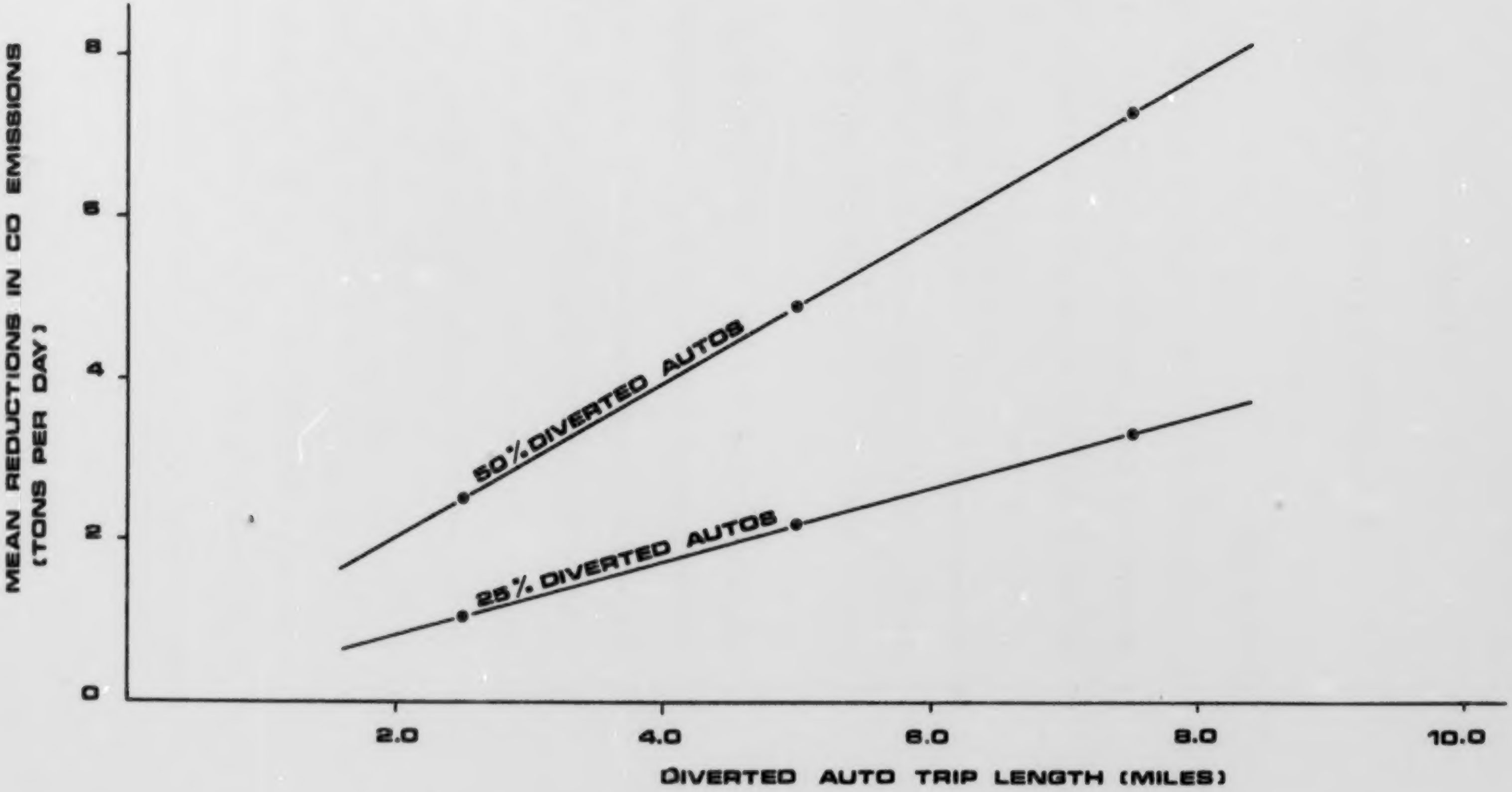


3.26

REDUCTION IN FUEL CONSUMPTION
ORANGE COUNTY, CALIF.

3.27

REDUCTION IN CO EMISSIONS
ORANGE COUNTY, CALIF.



CHAPTER 4

NEW CORRIDOR EXPRESS BUS SERVICE

4.1 INTRODUCTION

Four categories of corridor express bus service may be identified:

- Busways on Freeway Rights-of-Way--the modification of a freeway by the construction of new bus-only lanes or the screening off of existing lanes.
- Reserved Freeway Lanes--either in the peak flow direction or contra-flow where reverse direction traffic volumes are sufficiently light to permit 'wrong-way' bus operations on reserved lanes.
- Special Bus Ramps and Ramp Metering--the provision of special bus ramps to and from freeways or preferential bus entry to freeways that are controlled by ramp metering techniques.
- Arterial Bus Priority Treatments--includes the provision of exclusive bus lanes located along curbs or in street medians, and bus priority operation through pre-emption of traffic signals.

Any of the above categories can be altered by the incorporation of carpools onto the exclusive lane whether the lane be a concurrent or contra-flow lane, an exclusive on or off ramp, or a toll plaza bypass.

Major examples of the implementation of busway operations may be found throughout the United States. The two projects used for case study analysis are indicated with an asterisk, and will be discussed in greater detail following this introductory section and brief methodology description.

Busways

- Shirley Highway, Washington, D. C.*
- San Bernardino Freeway, Los Angeles*
- I-95, Miami

Reserved Freeway Lanes

- I-495 in New Jersey through the Lincoln Tunnel to N. Y. City
- U. S. 101 to the Golden Gate Bridge into San Francisco
- Long Island Expressway, New York City
- San Francisco Bay Bridge toll plaza bypass

Special Bus Ramps

- Blue Streak project, Seattle
- Commuter Club bus service, Reston, Virginia
- Harbor Freeway, Los Angeles

4.1.1 METHODOLOGY

Analysis of the fuel consumption savings and air pollutant emissions reductions associated with busway development projects was carried out using a computer simulation model (BUSWAY), which employed treatment of key input and output variables as having probability distribution functions, and not just single values. The distribution functions were developed to reflect the range of uncertainty associated with input and output variables.

Table 4.1 summarizes the factors which affect the net energy conservation and air quality impacts of busway development and operations. The table indicates which of these factors have been programmed in BUSWAY, the extent of BUSWAY analyses conducted, factors for which some data is available but not included in project studies, and factors for which no data has been found.

BUSWAY assumes a corridor configuration as shown in Figure 4.1. It further incorporates assumptions that (1) passenger demand is uniformly distributed within the specified service area which means that approximately the same number of buses enter the busway at each entry point, and (2) buses circulate through a portion of the service area for passenger collection and distribution before entering the busway. While it is believed that the reported results are significant and that input data has been carefully prepared, it is cautioned that findings are dependent on some data items for which little or no empirical data exists and on assumptions employed in the simulation model regarding corridor and bus service characteristics.

Energy savings are expressed in equivalent gallons of refined gasoline with bus diesel fuel consumption converted for case studies analysis.

4.2 SHIRLEY HIGHWAY BUSWAY

Initial busway operation started September, 1969 with continuing improvements through the present time. The busway is a double, reversible lane (both lanes inbound in the a.m., outbound in the p.m.), 11 miles long,

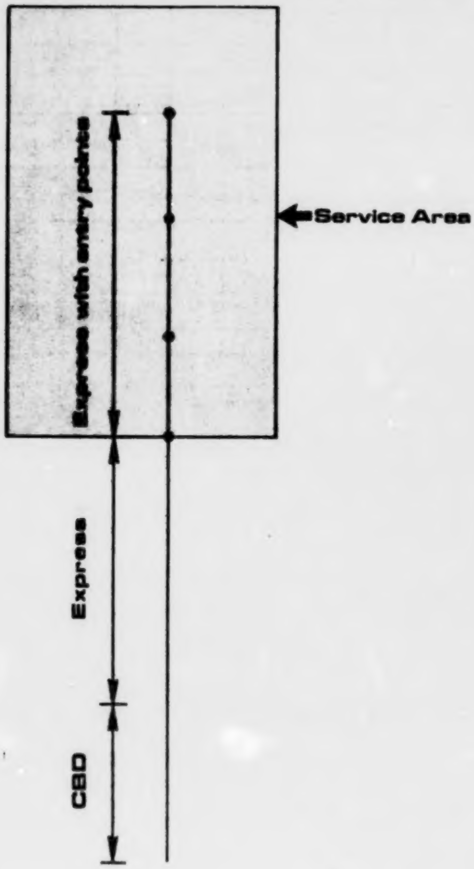
TABLE 4.1

FACTORS AFFECTING ENERGY CONSUMPTION AND AIR POLLUTANT EMISSION CHANGES FOR NEW EXPRESS BUSWAY SERVICE

		DATA AVAILABLE			MODEL ANALYSIS			
		SHIRLEY BUSWAY	SAN BERNARDINO BUSWAY	OTHER	INPUT	RANDOM VARIABLE	PARAMETRIC ANALYSIS	OUTPUT
BUS RIDERSHIP	NEW RIDERSHIP	●	●		●			
	PEAK PERIOD	●				●		
	OFF-PEAK LOAD FACTOR	●						
	PREVIOUS TRAVEL MODE INCLUDING DIVERSION FROM CARPOOLS	●	●					
CORRIDOR SERVICE DESCRIPTION	LENGTH OF BUSWAY	●	●		●			
	CORRIDOR TRIBUTARY AREA	●	●		●			
	ENTRY/EXIT SPACING	●	●		●			
	BUS UNIT FUEL CONSUMPTION			●		●		
	BUS UNIT CO EMISSIONS			●		●		
AUTO DIVERSION	NUMBER OF AUTOS DIVERTED	●	●		●	●		
	DIVERTED AUTO TRIP LENGTH					●		
	TIME OF DAY OF DIVERTED AUTOS	●	●					
	REGIONAL LOCATION OF DIVERTED AUTO TRIPS	●	●					
	DIVERTED AUTO UNIT GASOLINE CONSUMPTION			●		●	●	
	DIVERTED AUTO UNIT EMISSIONS			●		●	●	
FORMER BUS RIDERS	NUMBER OF TRIPS DIVERTED FROM FORMER BUS SERVICE	●	●		●	●		
	FORMER BUS SERVICE LOAD FACTOR	●		●		●		
	BUS UNIT FUEL CONSUMPTION			●		●		
	BUS UNIT EMISSIONS			●		●		
ACCESS MODE	NUMBER OF PARK-AND-RIDE PASSENGERS	●	●		●	●		
	NUMBER OF KISS-AND-RIDE PASSENGERS	●	●		●	●		
	NUMBER OF FEEDER BUS PASSENGERS	●	●		●	●		
	UNIT FUEL CONSUMPTION FOR AUTO ACCESS TRIPS			●		●	●	
	UNIT EMISSIONS FOR AUTO ACCESS TRIPS			●		●	●	
	FEEDER BUS UNIT FUEL CONSUMPTION			●		●		
	FEEDER BUS UNIT EMISSIONS			●		●		
LONG TERM IMPACTS	RESIDENCE LOCATION CHANGE	●	●					
	REDUCED AUTO OWNERSHIP							
	REDUCED TRAFFIC CONGESTION							
	OTHER USE OF AUTO		●					
OUTPUT	NET 1975 HC EMISSIONS REDUCTION							●
	NET 1975 FUEL SAVINGS							●
	NET FUEL SAVINGS WITH IMPROVED AUTOS							●
	NET 1975 CO EMISSIONS REDUCTION							●

4.1

GENERALIZED BUSWAY MODEL


Express with entry points
Service Area
Express
CBD

built into the median strip of the freeway (see Figure 4.2). Most bus lines routed via the busway circulate through neighborhood areas prior to entering the busway, although several park-and-ride lots are located along the length of the busway.

Ridership counts have been made periodically to measure growth, and a.m. peak period ridership has risen from an initial 1900 passengers to 11,500 passengers as of October, 1974, representing approximately 40 percent of all peak period person trips in the freeway corridor. Since its opening, construction in conjunction with freeway widening has caused significant traffic congestion through two-lane bottleneck sections of the adjoining freeway. Under these conditions, bus users have enjoyed additional travel time savings which may be removed when construction is completed.

Input data for study analysis has been derived from the results of an on-board bus survey conducted in Fall, 1973[1] plus additional information from earlier reported surveys carried out by the National Bureau of Standards Technical Analysis Division[2].

4.2.1 DIVERSION FROM AUTO DRIVING

Approximately 40 percent of the bus trips made on the Shirley busway each day were formerly automobile trips, made either in the Shirley Highway corridor or in some other part of the region prior to a change in residence

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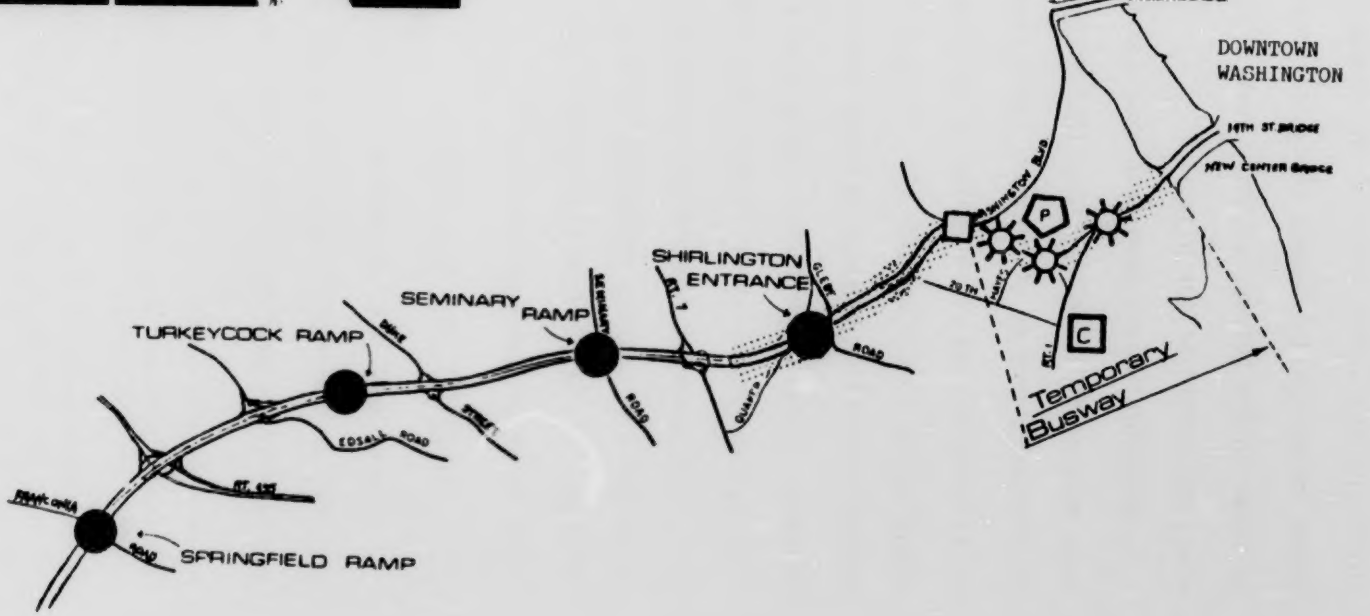
[1] Personal communication with the Technical Analysis Division, National Bureau of Standards.

[2] U. S. Department of Transportation, Urban Mass Transportation Administration. The Shirley Highway Express Bus-on-Freeway Demonstration Project--Second Year Results. November, 1973.

4.2

SHIRLEY HIGHWAY BUSWAY WASHINGTON


MEMORIAL BRIDGE
DOWNTOWN WASHINGTON
14TH ST. BRIDGE
NEW CENTER BRIDGE
WASHINGTON BLVD
P
20TH
NAVY
C
ST. 1
Temporary Busway
SHIRLINGTON ENTRANCE
GLEBE ROAD
RT. 7
QUAKER
SEMINARY RAMP
SEMINARY ROAD
TURKEYCOCK RAMP
DUKE STREET
EDSALL ROAD
RT. 495
FRANCONIA ROAD
SPRINGFIELD RAMP

location (see Table 4.2). Of the remainder, an estimated 35 percent previously used other regional bus service and 15 percent were auto passengers, either as part of a car pool or as a regular passenger with a spouse or other individual.

4.2.2 BUSWAY ACCESS MODE

One of the key factors in evaluating the energy savings and CO emissions reduction of busway and rail transit corridor systems is the mode of access used to reach the corridor system. For the Shirley busway, survey results indicate that nearly one-third of the busway users drive or are driven to use the busway service. This continued auto use, involving a 'cold start', is significant in lowering the potential impact on energy savings and air pollutant emissions. The access mode breakdown for the Shirley busway is summarized in Table 4.3.

4.2.3 BUSWAY INFLUENCE ON RESIDENCE LOCATION CHOICE

Nearly 75 percent of the busway users have located within the Shirley Highway corridor within the preceding five years. Of this group, approximately 37 percent expressed that the availability of busway service had a 'definite' influence on their residence location decision. An additional 19 percent indicated that its availability had a 'slight' influence, while the largest portion of new residents using the busway responded that it had 'no' effect on their new residence location.

The development of the Shirley busway and other major fixed transit facilities may exert a strong influence toward energy consumption and pollutant emissions levels via their influence on land use patterns,

TABLE 4.2

PREVIOUS TRAVEL MODE OF SHIRLEY BUSWAY RIDERS, A.M. PEAK PERIOD

	Old Residents(b)		New Residents(b)	
Mode	Number	Percent	Number	Percent
Auto Driver	1860	16		
Carpool Driver	300	3	3220	28
Alternate Carpool Driver	480	4		
Auto Passenger	420	4		
Bus	1000	9	3070	27
Other	610	5	520	5
TOTAL	4700	41	6800	59

Note: (a) Totals may not add due to rounding

(b) New residents are those who have located in the Shirley Corridor following introduction of busway service.

TABLE 4.3

MODE OF ACCESS FOR SHIRLEY BUSWAY RIDERS, A.M. PEAK PERIOD

Mode	Number	Percent
Park and Ride	2710	24
Walk	7760	67
Dropped Off	1010	9
Other	120	1
TOTAL	11,500	100

hypothesized to tend to encourage higher development densities. The cited survey findings are not sufficient for judging whether or not the Shirley busway has generated net positive or negative impacts in this regard.

4.2.4 BUSWAY PASSENGER LOAD FACTORS

Buses using the Shirley busway during morning and afternoon peak periods carried an average of approximately 49 passengers according to June, 1974 survey results. Buses have a seated capacity of 47 to 52 passengers depending on the seat configuration. Note that in deadheading or making a scheduled trip in the reverse direction, passenger loads will be zero or small, thereby reducing the average load factor by approximately one-half. For bus service operated on parallel arterials within the corridor, passenger loads in the peak direction averaged between 26 and 42 per bus counted in June, 1974. During off-peak periods, buses operating in the corridor average less than 10 passengers per bus at the maximum load point.

These load factors were utilized as input to BUSWAY runs for both the Shirley and San Bernardino busway case studies.

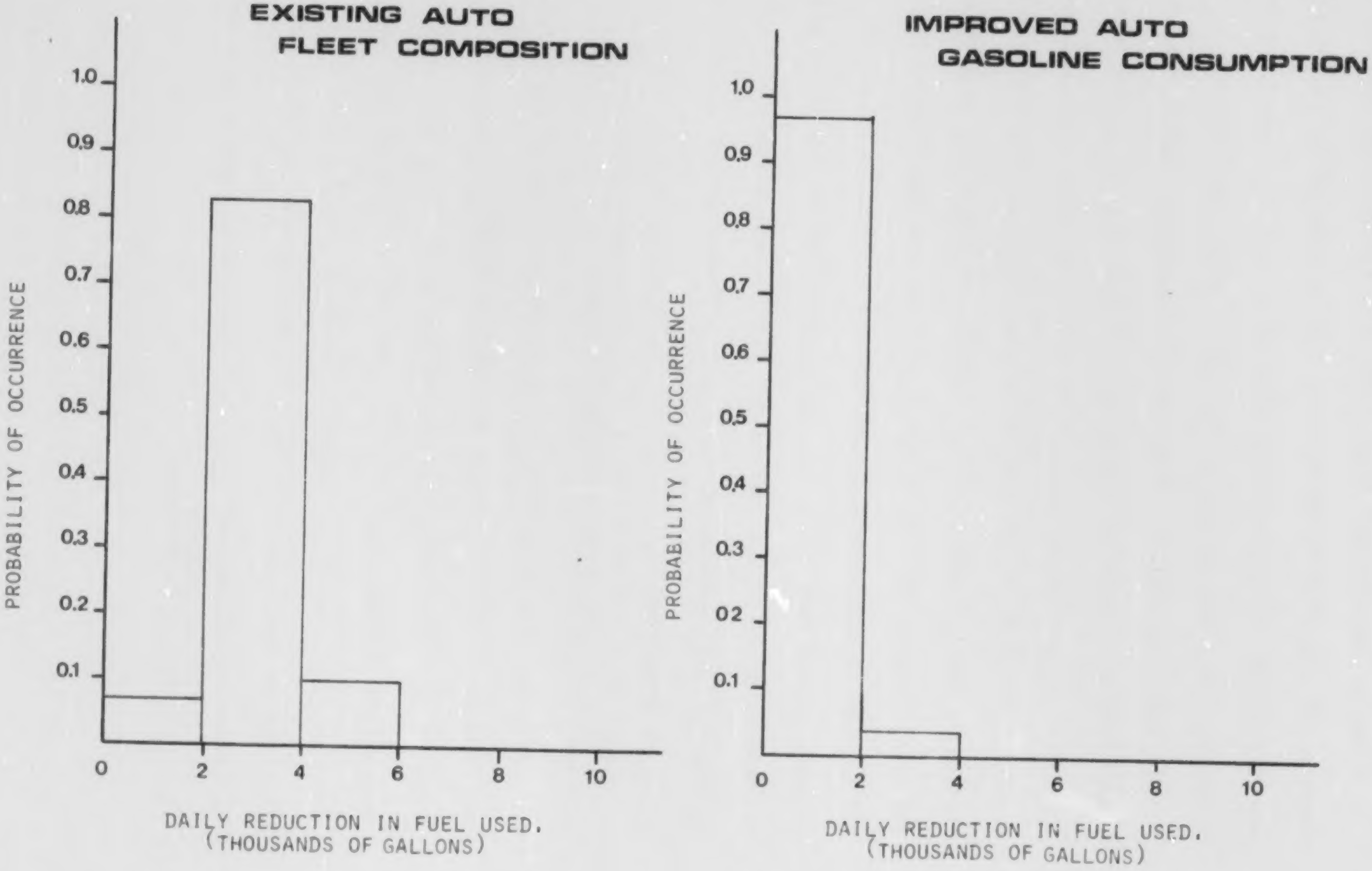
4.2.5 NET ENERGY CONSUMPTION SAVINGS

It is estimated that the Shirley busway has generated a net fuel consumption savings of approximately 3,100 gallons per day, with 99-percent probability that the amount of savings has not been less than 1300 gallons or in excess of 4,800 gallons as illustrated in Figure 4.3.

For comparison, recall that the areawide bus service improvements for the Washington area generated an energy savings of only 250 gallons per day with significant probability of actual increase conditions depending on auto diversion characteristics.

4.3

SHIRLEY BUSWAY DAILY FUEL SAVINGS



EXISTING AUTO FLEET COMPOSITION

IMPROVED AUTO GASOLINE CONSUMPTION

Assuming that diverted autos consume 40 percent less gasoline on the average, the distribution of expected fuel savings shifts resulting in mean savings of 1,200 gallons per day, or a range of between approximately 50 gallons and 2,400 gallons of fuel saved daily (see Figure 4.3).

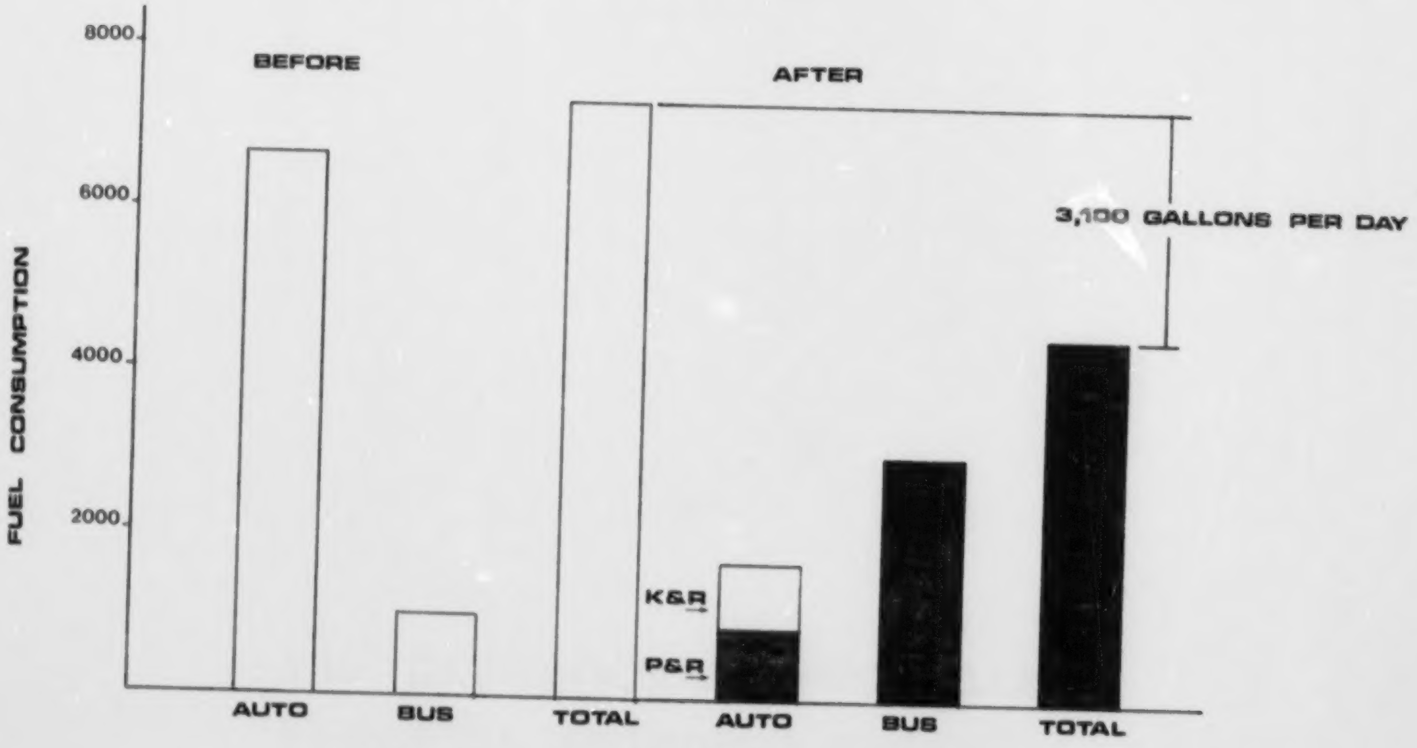
Further investigation of energy use components 'before' and 'after' busway opening illustrates the effects of auto use for system access and increased bus operations on potential energy savings. Elimination of approximately 9,200 daily auto trips accounts for a potential gasoline savings of nearly 7,000 gallons. However, increased bus fuel consumption and gasoline used for auto trips to and from the busway serve to reduce net savings to approximately 3,100 gallons as shown in Figure 4.4. If it were assumed that all busway users were diverted from autos with an average occupancy of 1.4 persons per auto, a fuel savings of about 13,000 gallons per day, instead of the actual estimated amount of 3,100 gallons, would be determined.

4.2.6 NET AIR POLLUTANT EMISSIONS REDUCTION

Assuming 1975 automobile fleet composition, use of the Shirley busway has reduced CO emissions by an average amount of 3.5 tons per day (see Figure 4.5). This represents a contribution of about ten percent towards meeting the maximum eight hour CO reduction assumed for Vehicle Miles Traveled (VMT) reduction measures as part of the transportation control strategy for the Washington region to meet ambient air quality standards by 1975. Hydrocarbon emissions have also been reduced by approximately 50 kg per day on the average.

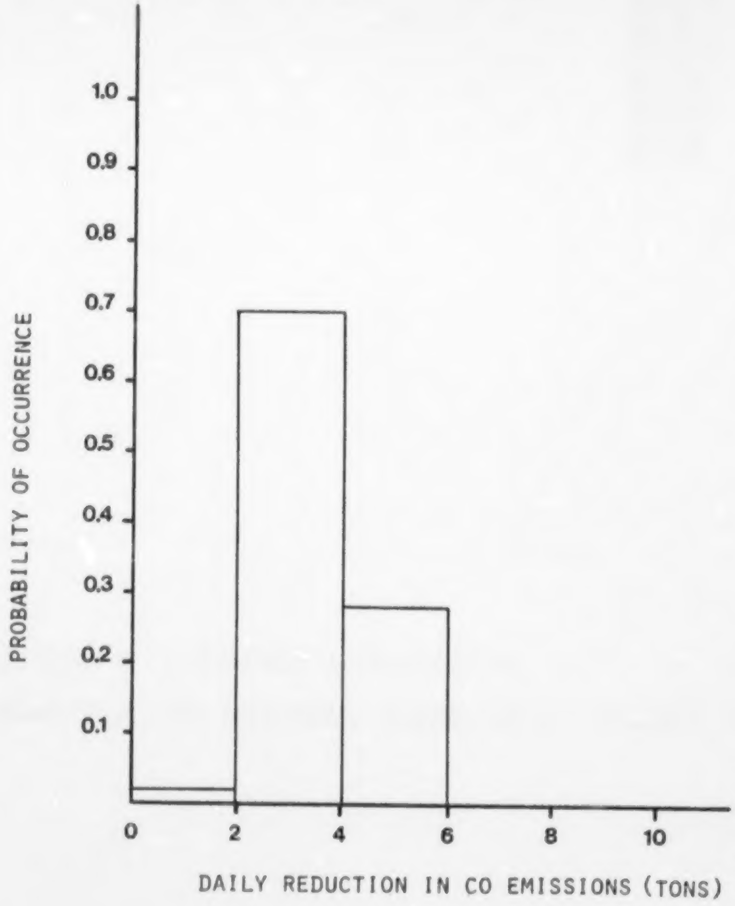
4.4

SHIRLEY BUSWAY BEFORE AND AFTER ENERGY CONSUMPTION



4.5

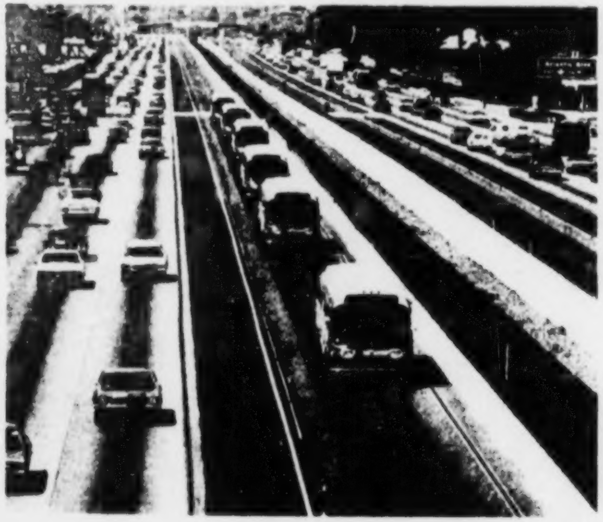
SHIRLEY BUSWAY DAILY CO EMISSIONS REDUCTION



4.3 SAN BERNARDINO BUSWAY

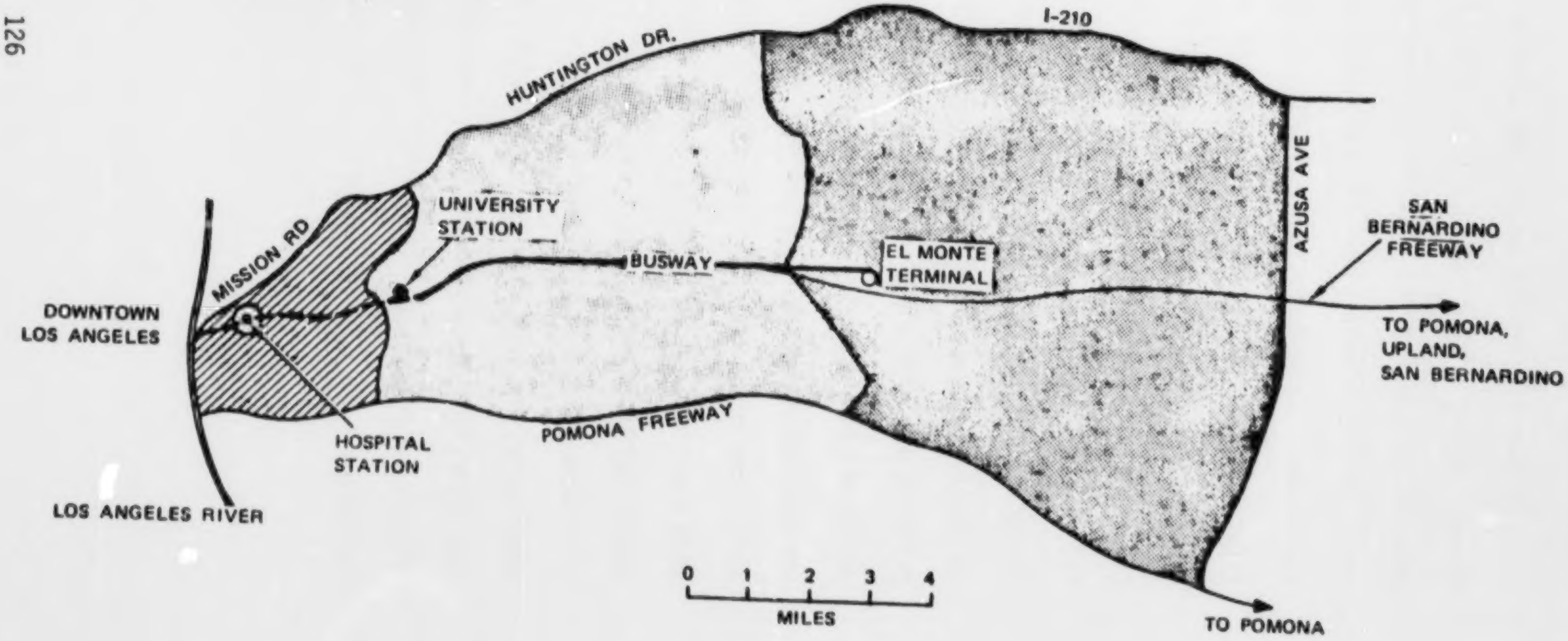
The San Bernardino busway has been constructed along a railroad right-of-way, either within the median or adjacent to the San Bernardino freeway east of the Los Angeles central business district (see Figure 4.6). It is approximately eleven miles in length and has two lanes with bi-directional operations. In contrast with Shirley busway operations in which buses enter the busway at several intermediate locations following a turn off the busway for passenger collection, San Bernardino busway operations are focused at a single terminal located at the eastern terminus of the busway. The El Monte terminal provides parking for over 1,500 automobiles as well as facilities for transferring from feeder buses and 'kiss-and-ride' access. In addition, buses using the busway are routed through adjacent communities prior to arriving at the El Monte terminal to pick up transferring passengers and continuing into downtown Los Angeles. Two intermediate stations, one located adjacent to California State University at Los Angeles (3.5 miles from downtown) and the second at the County Hospital (about two miles from downtown), were recently opened as additional destination points for busway service.

Busway ridership has increased from approximately 500 passengers at opening in January, 1973 to about 4,800 passengers in February, 1975 during the three hour a.m. peak period. The system has sustained two years of continuous patronage growth, with this growth enhanced by improvements including a fare reduction to 25 cents and the introduction of contra-flow



4.6

SAN BERNARDINO BUSWAY LOS ANGELES


I-210
HUNTINGTON DR.
AZUSA AVE
SAN BERNARDINO FREEWAY
MISSION RD
UNIVERSITY STATION
BUSWAY
EL MONTE TERMINAL
DOWNTOWN LOS ANGELES
TO POMONA, UPLAND, SAN BERNARDINO
HOSPITAL STATION
POMONA FREEWAY
LOS ANGELES RIVER
0
1
2
3
4
MILES
TO POMONA

bus lanes in downtown. Current ridership represents about a thirty percent share of total peak period person trips made in the corridor.

Looking at peak period, peak direction person trips, the busway volume is now approximately 60 percent of the volume carried by one of the parallel freeway lanes.

Input data for the case study analysis has been provided from on-board surveys carried out in November, 1974 by Bigelow-Crain Associates for the Southern California Association of Governments (SCAG) and via contact with the Southern California Rapid Transit District. Additional information describing first-year operating results was also available from earlier surveys conducted by Crain & Associates for SCAG[1]. A review of key input data items and case study analyses follows.

4.3.1 DIVERSION FROM AUTO DRIVING

The November, 1974 survey results regarding the former mode of San Bernardino busway users are summarized in Table 4.4. Adjusting for those respondents who indicated the busway as their only mode of travel, approximately 79 percent of all riders have been diverted from auto driving, representing 5,200 autos removed from the freeway and parallel corridor arterials during the a.m. peak period. This is nearly twice the shift noted from the Shirley busway, with the difference primarily attributable to greater existing bus ridership prior to busway opening in the latter instance.

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[1] Crain & Associates. "First Year Report--San Bernardino Freeway Express Busway Evaluation". Draft Report prepared for the Southern California Association of Governments, January, 1974.

TABLE 4.4

PREVIOUS TRAVEL MODE OF SAN BERNARDINO BUSWAY USERS

Previous Mode	Number	Percent
Always used busway	650	10
Auto Driver (alone)	3830	59
Auto Driver (with passengers)	450	7
Auto Passenger	720	11
Alternate Carpool Driver	720	11
Non-busway Bus	130	2
TOTAL	6500[(a)]	100

Note: (a) Estimated total weekday ridership, February 1975

Source: November, 1974 on-board survey conducted by Bigelow-Crain Associates for the Southern California Association of Governments.

Nearly one-third of the busway users formerly traveled in an automobile carrying two or more persons. However, the average auto occupancy for all automobile trips diverted to the busway is approximately 1.24 persons per auto, which is slightly lower than the estimated corridor average of 1.3 persons per auto. This difference does not appear to indicate that new transit users are more likely to have been carpool participants than not.

4.3.2 BUSWAY ACCESS MODE

In sharp contrast to Shirley busway access characteristics, approximately 72 percent of San Bernardino busway riders reach the system by automobile (see Table 4.5). This serves to reduce potential fuel savings and air quality improvement since an automobile trip involving a cold start is still made in the corridor.

Of the auto access total, over three-quarters (55 percent of total busway riders) use park-and-ride lots. For these users, the system does not provide full economic benefit due to reduction in household auto ownership requirements which may be possible for other new users.

4.3.3 USE OF AUTO LEFT AT HOME

To begin, recall that approximately 5,200 auto trips were diverted to the busway each day, but that nearly 3,100 autos are parked in park-and-ride lots each day. Then, assume that the difference (2,100 autos) represents a reasonable estimate of the number of autos left at home by former auto commuters. The November, 1974 survey inquired regarding the use of these autos and found that 61 percent were idle during the day.

TABLE 4.5

MODE OF ACCESS FOR SAN BERNARDINO BUSWAY USERS

Access Mode		Number	Percent
Park and Ride		3550	55
Walk		1500	23
Dropped Off		1100	17
Feeder Bus		350	5
	TOTAL	6500[a]	100

Note: (a) Estimated total weekday ridership, February, 1975.

Source: November, 1974 on-board survey conducted by Bigelow-Crain Associates for the Southern California Association of Governments.

his implies a limit for potential automobile ownership reduction of nearly 1,300 autos, a significant potential economic benefit directly attributable to development of the San Bernardino busway. This does not account for new busway users who may have replaced a commuting automobile with one in poorer repair for shorter access trips to the busway terminal.

The remaining 800 autos left at home during the day were used for a variety of trip purposes as summarized in Table 4.6. This added usage will serve to cancel some of the fuel savings and pollutant emissions reduction achieved by diversion to the busway to the extent that these auto trips were not previously made.

4.3.4 BUSWAY INFLUENCE ON RESIDENCE LOCATION CHOICE

The pre-busway survey carried out in April, 1972[1] inquired regarding the influence of bus service on residence location choice. Interestingly, the breakdown of responses are similar to those reported for the Shirley busway. Approximately 39 percent of the bus riders indicated that bus service availability had influenced their choice. About 19 percent responded that it had slight influence, while the greatest number (46 percent) answered that their residence location decision was based on non-transit factors.

No corresponding data was collected for persons changing residence location following busway opening and development.

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[1] Crain & Associates.

TABLE 4.6

USE OF COMMUTING CAR LEFT AT HOME

	Percent
Not used	61
Another person takes it to work	13
Shopping, errands	17
School, university	5
Other	4
TOTAL	100

4.3.5 NET ENERGY CONSUMPTION SAVINGS

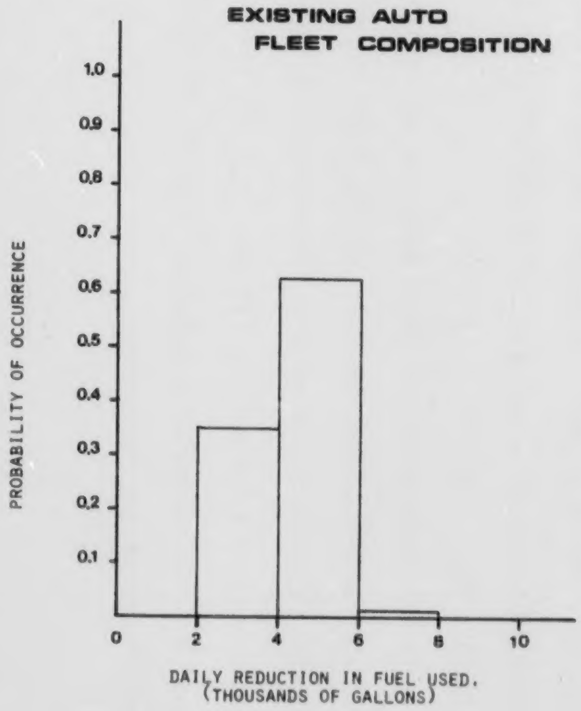
Application of BUSWAY using input data as already described for 1975 automobile fleet characteristics generated an expected fuel savings distribution as shown in Figure 4.7 with an average value of about 4,300 gallons per day, and less than one percent probability of savings less than 2,200 gallons or more than 6,300 gallons of fuel. Assuming a 40 percent improvement in auto gas consumption rates, the fuel savings distribution shifted with a lower mean savings of 2,100 gallons per day (see Figure 4.7).

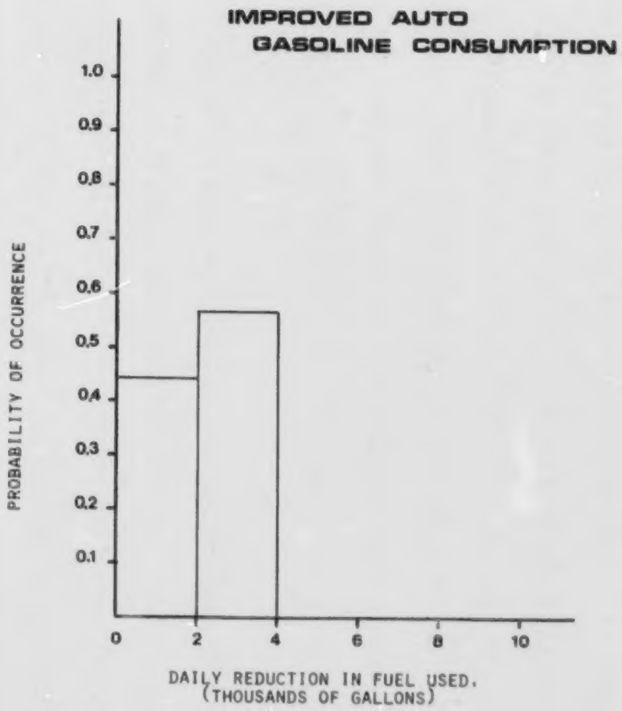
Recall that 800 autos left at home during the day are used for trips previously made. If this trip-making required an average of one gallon per day per auto, the estimated 1975 fuel savings would be reduced by approximately 20 percent to 2,500 gallons per day. The estimated savings with more efficient autos would be about 40 percent less or 1,300 gallons per day. This amount of fuel consumption represents additional travel of between 12 and 22 miles per day, which appears to be a reasonable value for induced trips.

Figure 4.8 summarizes estimated auto and bus energy use components 'before' and 'after' busway opening. As was found for the Shirley busway, the potential savings due to elimination of corridor auto trips is lowered from approximately 8,200 gallons per day to 3,500 gallons per day when increased bus fuel consumption and gasoline used for system access and induced auto trips are considered.

4.7

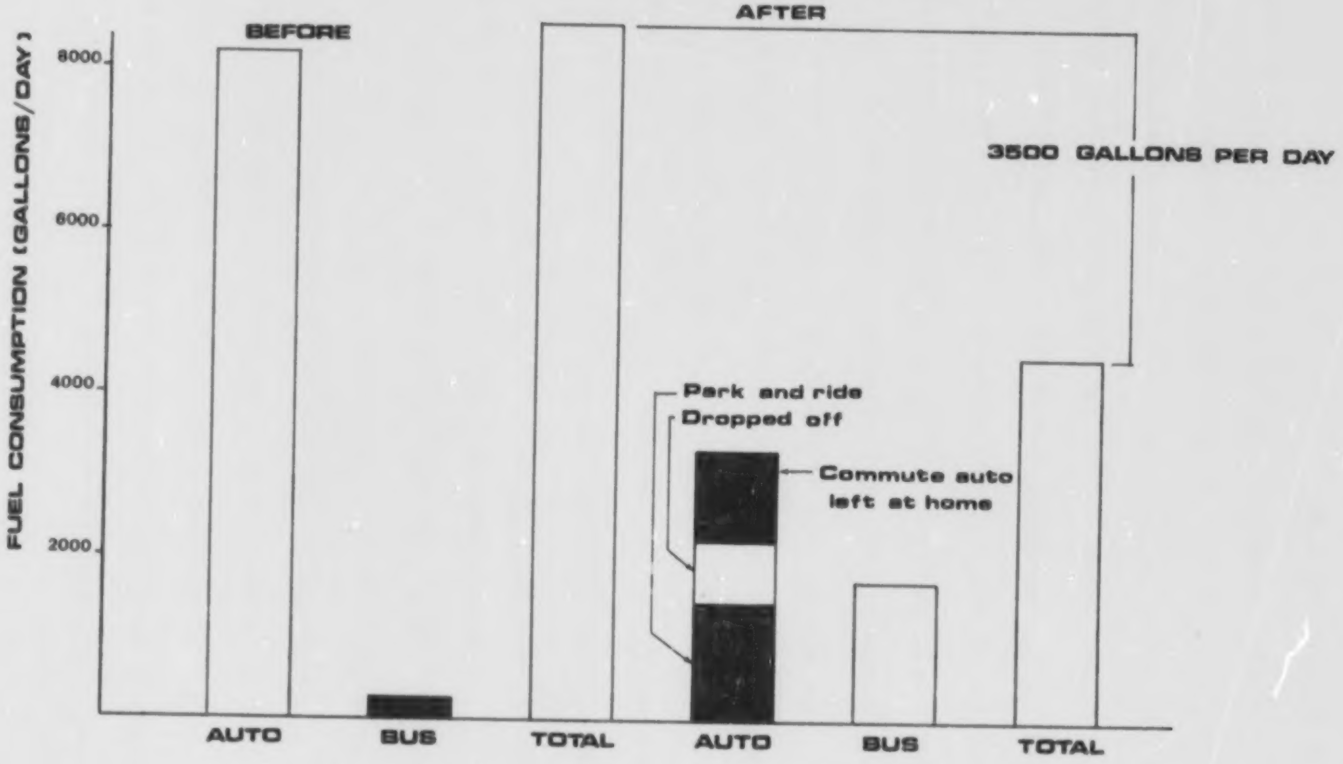
SAN BERNARDINO BUSWAY DAILY FUEL SAVINGS


EXISTING AUTO
FLEET COMPOSITION


IMPROVED AUTO
GASOLINE CONSUMPTION

4.8

SAN BERNARDINO BUSWAY BEFORE AND AFTER ENERGY CONSUMPTION

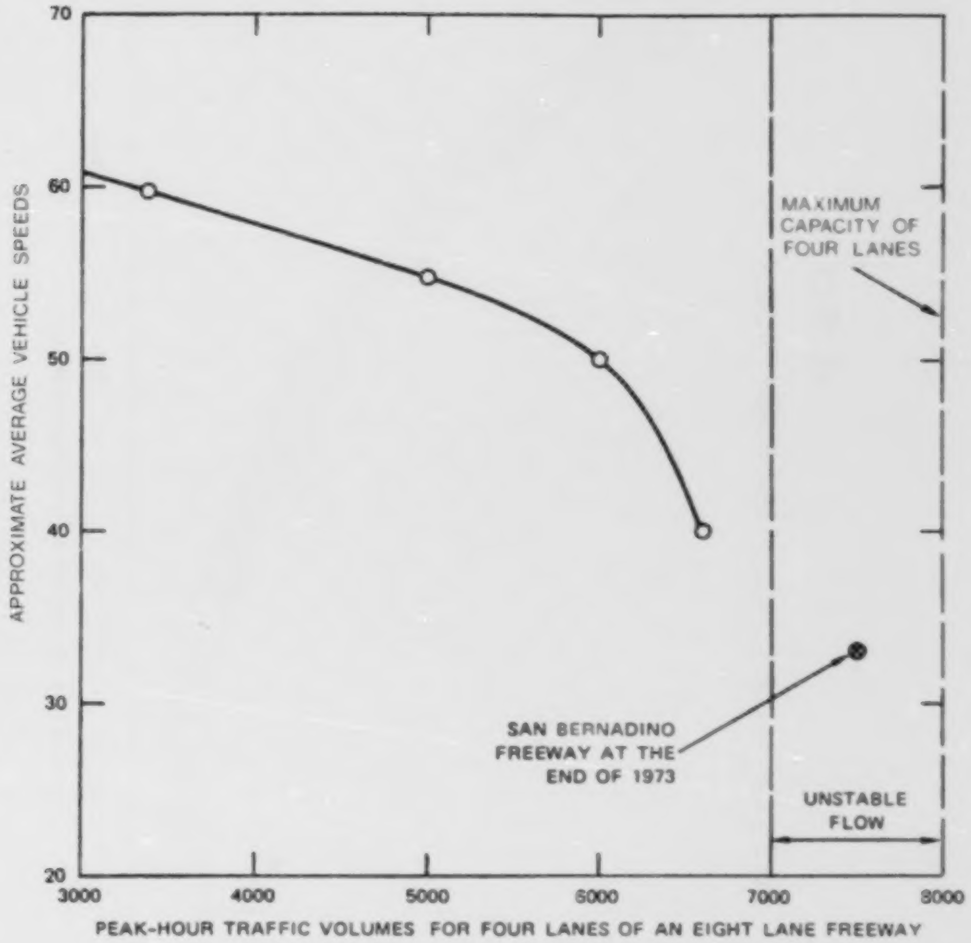


Another aspect of potential fuel savings (and CO emissions reduction) may overwhelm computed savings from diversion of auto trips to more efficient transit vehicles.

Traffic volumes on the San Bernardino freeway have been at or near maximum capacity for the last ten years. Volumes have ranged from about 140,000 to 170,000 vehicles per day in both directions. This volume is so high that speeds during the peak hours have been unstable with maximum speeds being between 30 and 35 mph. The implication of this unstable flow condition is that, if the busway were able to draw a sufficient number of drivers from their cars, freeway speeds would increase sufficiently to cause a significant increase in travel speed to the remaining auto users.

To indicate the volume-speed relationships more clearly, Figure 4.9 shows approximate peak hour volume-speed relationships for four lanes of an eight-lane freeway. The relationship shows that higher speeds occur when traffic volumes are low, and the speeds drop off sharply at higher volume levels (6000 to 7000 vehicles per hour). At volumes higher than 7000 vehicles per hour, the speeds become increasingly unstable and, at capacity, vary between zero and a few miles per hour (mph). The San Bernardino freeway peak hour volume is about 7500 vehicles, in the unstable flow range between 30 and 35 mph.

Assuming that one-half of the estimated 3800 auto trips diverted to the busway occured in the peak hour, the peak hour freeway volume would be only 5600 vehicles resulting in an average speed increase to approximately 50 mph. Referring to Figure 4.10 this speed change would improve average auto gasoline consumption by roughly 10 percent or about 0.7

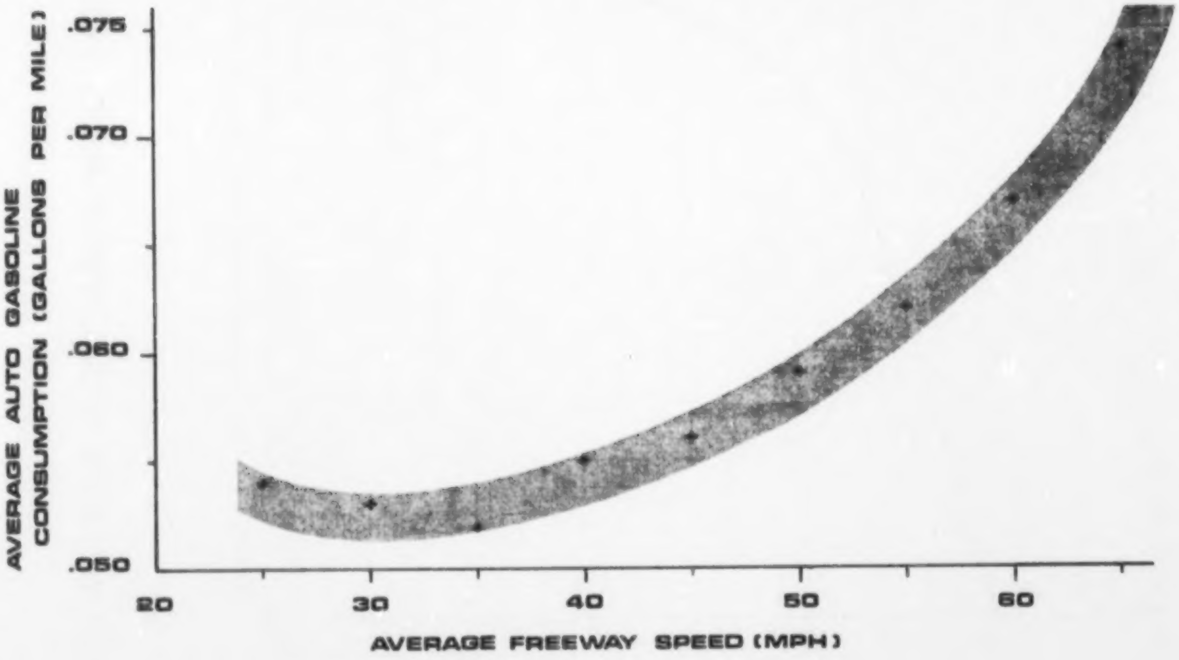


4.9

APPROXIMATE VOLUME-SPEED RELATIONSHIP

4.10

AUTO FUEL CONSUMPTION



gallons over the eleven mile corridor length. For all remaining autos during both the a.m. and p.m. peak hours only, a gasoline savings of 7,800 gallons would accrue. This is nearly double the average amount computed above without consideration of volume-speed relationships.

However, the hypothesized increases in freeway speeds may affect the route selection of other auto drivers. Some drivers on more circuitous routes paralleling the freeway are likely to switch to driving on the freeway. In this case, net speed increases may still occur on the freeway and perhaps result on the circuitous routes as well, generating net gasoline savings within the corridor. In addition, the peak period may shorten so that peak hour volumes remain approximately the same in response to improved flow conditions as drivers reschedule their individual trip times and additional fuel consumption savings do not occur. No data was available to confirm actual freeway conditions in the San Bernardino corridor. The potential magnitude of gasoline savings indicates that further studies should be undertaken in this area.

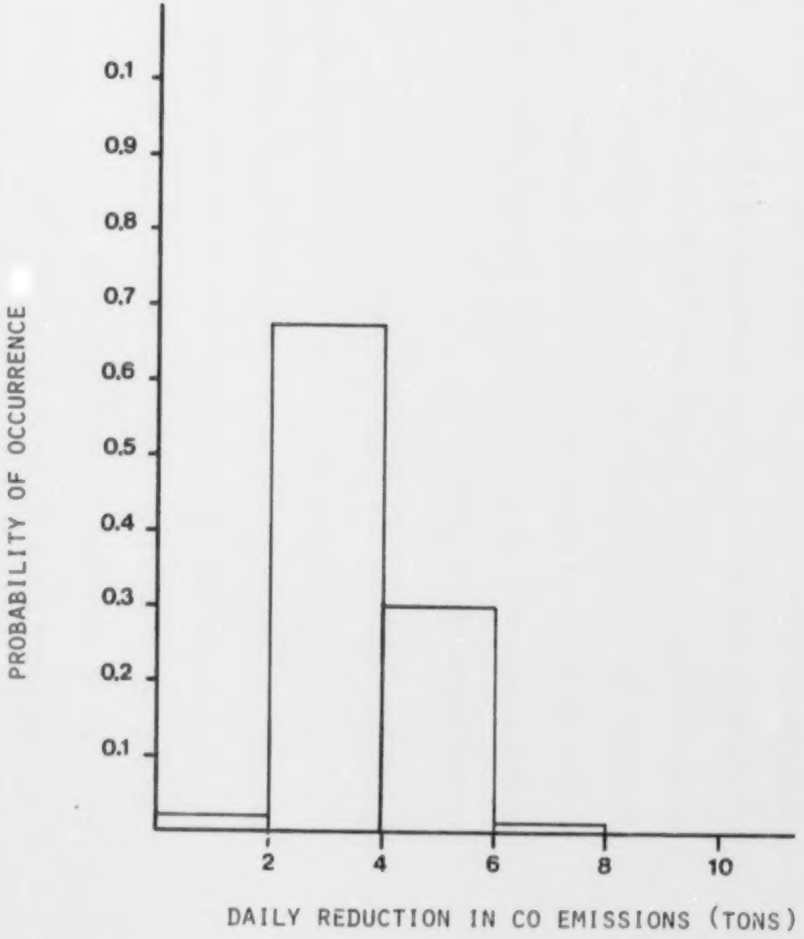
4.3.6 Net Air Pollutant Emission Reduction

Assuming unit emission factors representative of the 1975 national automobile fleet and different driving cycle conditions within the corridor, it is estimated that the San Bernardino busway development has reduced corridor CO emissions by an average amount of 3.5 tons per day (see Figure 4.11) and HC emissions by approximately 240 kg.

To place these estimates in perspective, the transportation control strategy for the Los Angeles region promulgated by the Environmental

4.11

SAN BERNARDINO BUSWAY DAILY CO EMISSIONS REDUCTION

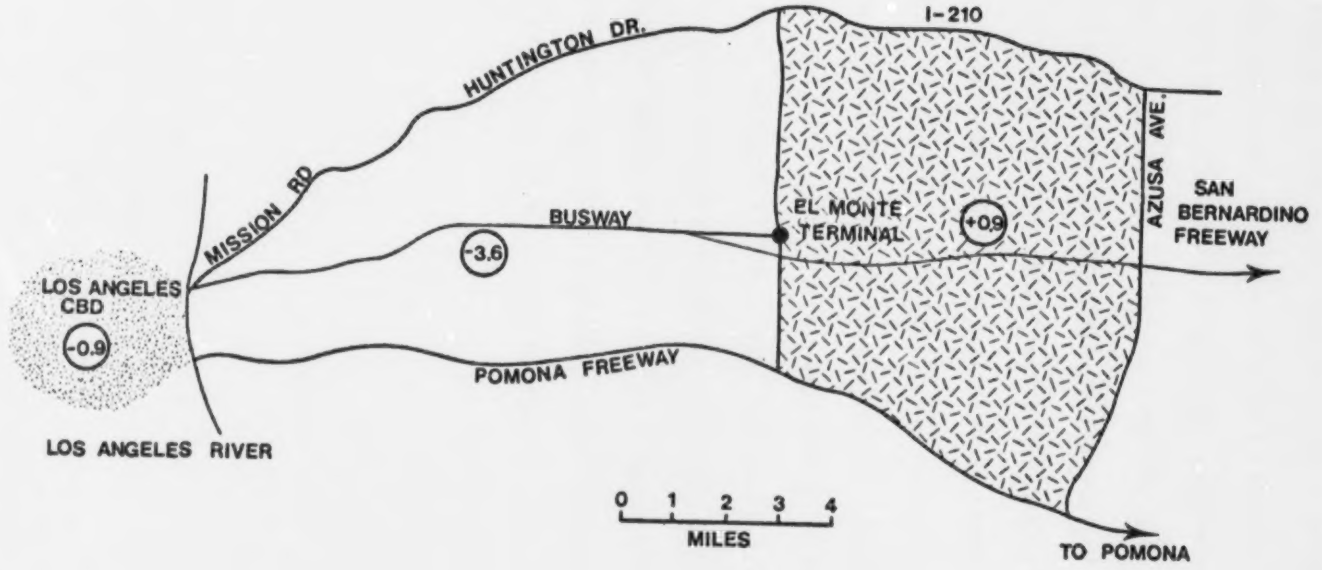


Protection Agency calls for a reduction of 550 tons of CO emissions per day through VMT reduction measures in order to meet 1977 ambient air quality standards. The contribution of the San Bernardino busway towards achievement of these standards would be less than one percent. The stringent measures required to meet standards in the Los Angeles area make plan implementation unlikely. Studies assessing the reasonableness of the Los Angeles 1977 implementation plan considered the maximum transit share (without auto restrictive measures) to be about 80 tons for the region. In this context, the busway is contributing less than four percent towards attainment.

Figure 4.12 illustrates that the estimated air pollutant emissions reductions actually include worsened conditions in suburban areas adjacent to the El Monte terminal. For CO emissions, a net reduction of 4.4 tons results along the busway and in downtown, but an increase of approximately 0.9 tons occurs in the outer corridor suburbs. For HC emissions, a similar pattern results with an increase of approximately 40 kg in the El Monte terminal vicinity. However, the polluting effects of HC occur with formation of regional photochemical oxidants and localized distribution effects are not significant.

4.12

SAN BERNARDINO BUSWAY DISTRIBUTION OF CO CHANGES


I-210
HUNTINGTON DR.
MISSION RD
AZUSA AVE.
SAN BERNARDINO FREEWAY
BUSWAY
EL MONTE TERMINAL
+0.9
-3.6
LOS ANGELES CBD
-0.9
POMONA FREEWAY
LOS ANGELES RIVER
TO POMONA
0 1 2 3 4
MILES

CHAPTER 5
NEW CORRIDOR RAIL TRANSIT SERVICE

5.1 INTRODUCTION

This report chapter considers the potential energy consumption savings and air quality improvements which may be derived from new corridor rail transit service. At the present time, major rail transit system development projects are underway in several large U. S. cities including Atlanta, Baltimore, and Washington, D. C. Two case studies were selected for review in this study phase--Bay Area Rapid Transit (BART) in the San Francisco Bay area and the Lindenwold High-Speed commuter rail line in the Philadelphia metropolitan area. Both are modern rail transit service examples, representing the current state-of-the-art in high technology and performance standards.

Before describing data and analyses carried out regarding a comparison of the energy and air pollutant emission characteristics of rail transit, some background information on two key aspects relating to comparisons with other transit modes should be introduced. First, any comparison of relative energy usage must differentiate between petroleum and non-petroleum energy consumption. Electric energy may be developed from either petroleum sources or hydroelectric, nuclear, coal, geothermal, and other non-petroleum sources. Hence, electrically-powered transit systems offer a greater degree of versatility in terms of energy source than either gasoline or diesel powered buses. Second, there are substantial inefficiencies associated with the generation and transmission of electrical power. To provide a true basis for comparison, it is necessary to consider requirements for 'source' energy (i.e., the energy equivalents in BTU's of the primary fuels). While estimates of these losses vary, source energy consumption may be expected to be 3.0 - 3.5 times system energy requirements.

5.1.1 METHODOLOGY

For analysis of the Lindenwold High-Speed line, a model (CORAIL) similar to that used for busway studies was employed. It invoked most of assumptions regarding corridor and service characteristics already outlined for BUSWAY in Chapter 4, although specification of feeder bus access to the line haul system was permitted. Key factors affecting potential energy savings and air pollutant emissions reduction were incorporated as summarized in Table 5.1.

It was found that only preliminary data regarding BART was available without undertaking more extensive data collection than possible for this study. Furthermore, CORAIL was developed for corridor applications and could not be used for BART system analysis. Some data tabulations for key factors have been included for comparison with corresponding data for other transit improvement projects.

5.2 BAY AREA RAPID TRANSIT (BART)

BART has achieved considerable publicity, both positive and negative, since its opening in September, 1972. The system encompasses 75 miles of modern, high-speed rail transit serving San Francisco, Oakland, and other east bay communities in the San Francisco Bay area .

TABLE 5.1

FACTORS AFFECTING ENERGY CONSUMPTION AND AIR POLLUTANT EMISSION CHANGES FOR NEW RAIL TRANSIT SERVICE

		DATA AVAILABLE			MODEL ANALYSIS			
		BART	LINDENWOLD	OTHER	INPUT	RANDOM VARIABLE	PARAMETRIC ANALYSIS	OUTPUT
TRANSIT RIDERSHIP	NEW RIDERSHIP		●		●			
	PEAK PERIOD LOAD FACTOR					●		
	OFF-PEAK LOAD FACTOR							
	PREVIOUS TRAVEL MODE INCLUDING DIVERSION FROM CARPOOLS	●	●					
CORRIDOR SERVICE DESCRIPTION	LENGTH OF LINE		●		●			
	CORRIDOR TRIBUTARY AREA		●		●			
	STATION SPACING		●		●			
	RAIL TRANSIT UNIT ENERGY CONSUMPTION	●	●			●		
	RAIL TRANSIT UNIT EMISSIONS			●				
AUTO DIVERSION	NUMBER OF AUTOS DIVERTED	●	●		●	●		
	DIVERTED AUTO TRIP LENGTH		●		●			
	TIME OF DAY OF DIVERTED AUTOS	●						
	REGIONAL LOCATION OF DIVERTED AUTO TRIPS		●					
	DIVERTED AUTO UNIT GASOLINE CONSUMPTION			●		●	●	
	DIVERTED AUTO UNIT EMISSIONS			●		●	●	
FORMER BUS RIDERS	NUMBER OF TRIPS DIVERTED FROM FORMER BUS SERVICE	●	●		●	●		
	FORMER BUS SERVICE LOAD FACTOR	●		●		●		
	BUS UNIT FUEL CONSUMPTION			●		●		
	BUS UNIT EMISSIONS			●		●		
ACCESS MODE	NUMBER OF PARK-AND-RIDE PASSENGERS	●	●		●	●		
	NUMBER OF KISS-AND-RIDE PASSENGERS	●	●		●	●		
	NUMBER OF FEEDER BUS PASSENGERS	●	●		●	●		
	UNIT FUEL CONSUMPTION FOR AUTO ACCESS TRIPS			●		●	●	
	UNIT EMISSIONS FOR AUTO ACCESS TRIPS			●		●	●	
	FEEDER BUS UNIT FUEL CONSUMPTION			●		●		
	FEEDER BUS UNIT EMISSIONS			●		●		
	ACCESS TRIP LENGTH		●		●	●		
LONG-TERM IMPACTS	RESIDENCE LOCATION CHANGE							
	REDUCED AUTO OWNERSHIP							
	REDUCED TRAFFIC CONGESTION	●	●					
	OTHER USE OF AUTO							
OUTPUT	NET 1975 CO EMISSIONS REDUCTION							●
	NET 1975 HC EMISSIONS REDUCTION							●
	NET 1975 FUEL SAVINGS							●
	NET FUEL SAVINGS WITH IMPROVED AUTOS							●

BART is currently the subject of an intensive impacts analysis research program including a detailed assessment of regional energy consumption and air quality implications. In this section, selected data items describing BART ridership characteristics including estimated auto diversion and system access mode are presented. It should be pointed out that BART is still moving towards full system operation, and the following data tabulations should be treated as preliminary in this regard.

5.2.1 CORRIDOR MODE CHOICE AND DIVERSION TO BART

BART initiated transbay service into San Francisco in September, 1974 with an immediate effect on transbay corridor trip patterns. For the peak period, a comparison of transit passenger counts and San Francisco Bay Bridge traffic volumes[1] (taken prior to BART service introduction and following it in October 1974) indicates that:

- total peak period corridor trips have remained approximately constant;
- corridor transit mode choice has increased from 46.5 percent to 48.8 percent using BART and bus service; and
- the increased total transit usage may be explained by reduced average auto occupancy, although both changes are small and may be due to normal data fluctuations.

Table 5.2 lists the number of trips transported by each mode during the two-hour a.m. peak period. For all day, it appears that BART may be generating new trips or absorbing new trips which would have mode in any case:

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[1] Institute of Transportation and Traffic Engineering, University of California at Berkeley.

TABLE 5.2

SAN FRANCISCO EAST BAY MODE SPLIT
A.M. PEAK PERIOD

		Passengers				
	Autos	Auto	BART	Bus	Total	Percent Transit
April, 1974	16,664	25,348	0	22,039	47,387	46.5
October, 1974	16,244	24,145	9,291	13,676	47,112	48.8
Percent Change	-3	-5	n/a	-37	-1	

Source: Institute of Transportation and Traffic Engineering, University of California at Berkeley.

- the total number of daily corridor trips has increased by about eight percent with automobile trips remaining approximately constant;
- corridor transit mode choice has increased from 22.1 percent to 27.1 percent using BART and bus service; and
- new BART ridership may be accounted for as being about three-fifths diverted from bus service, and two-fifths trips not made six months previously.

The split of daily corridor trips by travel mode is summarized in Table 5.3.

5.2.2 PREVIOUS TRAVEL MODE

In addition to the inferences derived from the aggregate transbay corridor statistics which suggested no BART diversion from peak period automobile usage, the results of an onboard rider survey conducted in May, 1973 on the Richmond-Fremont BART line (prior to opening of east-west service including transbay operations) provides data regarding the prior mode of travel of BART users. These results, summarized in Table 5.4, show that approximately 39 percent of BART trips represent former automobile trips, and another 13 percent of the surveyed riders indicated that the trip had not been previously taken.

5.2.3 MODE OF BART ACCESS

As has already been noted, the degree of potential energy consumption savings and air pollutant emissions reduction due to the introduction of new corridor transit service may be effectively lowered by high auto use for system access. For BART's east bay line, nearly one-half of BART's

TABLE 5.3

SAN FRANCISCO EAST BAY MODE SPLIT
ALL DAY, BOTH DIRECTIONS

		Passengers				
	Autos	Auto	BART	Bus	Total	Transit
April, 1974	174,331	237,089	0	67,176	304,265	22.1
October, 1975	171,934	239,025	50,706	37,971	327,702	27.1
Percent Change	-1	+1	n/a	-44	+8	-

Source: Institute of Transportation and Traffic Engineering,
University of California at Berkeley.

TABLE 5.4

PREVIOUS TRAVEL MODE OF BART PASSENGERS, 1973

Previous Mode	Percent
Auto Driver	39
Auto Passenger	15
Bus	29
Other	5
Trip not made	12
TOTAL	100

Source: Office of Research, Bay Area Rapid Transit District.

passengers traveled to stations as an auto driver (35 percent) or were dropped off (13 percent). Only 14 percent used feeder bus service for system access, while the remainder arrived as auto passengers (11 percent), by walking (24 percent) or other means as summarized in Table 5.5. Further analysis of survey results showed that the mode of system access varied substantially from station to station along the line. At outlying suburban stations with adequate parking, the level of auto access was higher as would be expected. For example, over three-quarters of the passengers arriving at the Fremont station located at the southern terminus of the line drove automobiles or were dropped off.

5.3 LINDENWOLD RAPID TRANSIT

Since February 1969, the Philadelphia-Lindenwold line has provided high-speed access to the commercial centers of Camden and Philadelphia for commuters from the densely populated suburbs in South New Jersey. The 14.5 mile line extends from Lindenwold, New Jersey to Camden and over the Franklin Bridge to Philadelphia, and includes several advanced train technology elements including automatic train operations and automated fare collection.

The Federal Energy Administration, Office of Transportation Research is currently sponsoring a study intended to examine the energy consumption characteristics of the Lindenwold line including its potential impact assuming the line was not in operation. This study is scheduled for completion in May, 1975.

Selected data regarding Lindenwold line ridership characteristics which have a significant influence on the magnitude of potential energy consumption

TABLE 5.5

MODE OF BART ACCESS, 1973

Mode	Percent
Auto Driver	35
Auto Passenger	11
Dropped Off	13
Bus	14
Walk	24
Bicycle	2
Other	1
TOTAL	100

Source: Office of Research, Bay Area Rapid Transit District.

savings and air pollutant emissions reduction follows. This data is based on a series of on-board rider surveys performed by the Delaware River Port Authority (DRPA) in 1970, one year following service introduction.

5.3.1 CORRIDOR MODE CHOICE AND DIVERSION TO THE LINDENWOLD LINE

DRPA passenger survey indicated that the new Lindenwold service diverted approximately 8,500 daily automobile trips from bridge river crossings in 1970, representing about one-quarter of the daily system ridership of 30,000 passengers (see Table 5.6). Note that nearly twice as many of the new riderships were diverted from other transit modes. Examination of bridge traffic trend data does not confirm the decrease in auto trips expected from survey findings.

5.3.2 MODE OF ACCESS TO THE LINDENWOLD LINE

The 1970 on-board surveys found that ninety percent of all Lindenwold riders reached the system via auto. Of the auto access total, nearly three-quarters involved parking at station locations while the remainder were dropped off. Survey results are tabulated in Table 5.7.

5.3.3 ACCESS AND LINE HAUL TRIP LENGTHS

Working with the same survey results and passenger count data, Boyce, et al., estimated that the average airline distance for station access trips was 2-5 miles, depending on station location along the length of the line[1]. In comparison, the average transit line haul trip length was estimated to be approximately nine miles.

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[1] Boyce, D. E., et al. Impact of Access Distance and Parking Availability on Suburban Rapid Transit Station Choice. Prepared for the Office of the Secretary, U. S. Department of Transportation, PB 220 694, November, 1972.

TABLE 5.6

PREVIOUS TRAVEL MODE OF LINDENWOLD PASSENGERS, 1970

Previous Mode		Number	Percent
Auto Driver		8,500	28
Auto Passenger		3,500	12
Bus		10,800	36
Commuter Train		3,300	11
Trip not made		3,900	13
	TOTAL	30,000	100

TABLE 5.7

ESTIMATED MODE OF ACCESS FOR LINDENWOLD LINE USERS, 1970

Mode		Number	Percent
Park and Ride		10,100	67
Dropped Off		3,400	23
Feeder Bus		750	5
Walk		750	5
	TOTAL	15,000	100

5.3.4 NET ENERGY CONSUMPTION SAVINGS[1]

From simulation analysis using described data inputs, it was estimated that the Lindenwold line is producing an average peak period energy savings equivalent to approximately 800 gallons with four percent probability of increased energy consumption when possible variations in diverted auto trip and gasoline consumption characteristics are considered (see Figure 5.1).

If a forty percent improvement in automobile gasoline consumption is assumed, the estimated probability of increased overall energy use is approximately 30 percent with average peak period savings of only 200 gallons (see Figure 5.2).

Figure 5.3 summarizes energy consumption 'before' and 'after' Lindenwold line development, as was presented in the preceding chapter for the Shirley Highway and San Bernardino busways. In this case, auto gasoline consumption for system access is approximately one-half of the estimated amount of gasoline saved by autos diverted from commuting. If all Lindenwold line riders were assumed to be former auto commuters, a net peak period energy savings of approximately 5,700 gallons would be obtained. Since only 40 percent of new riders previously commuted by automobile, the resultant energy savings are substantially lower.

5.3.5 NET AIR POLLUTANT EMISSIONS REDUCTION

Assuming 1975 national automobile fleet characteristics, model results indicate peak period CO emissions reduced by approximately 1.3 tons and HC

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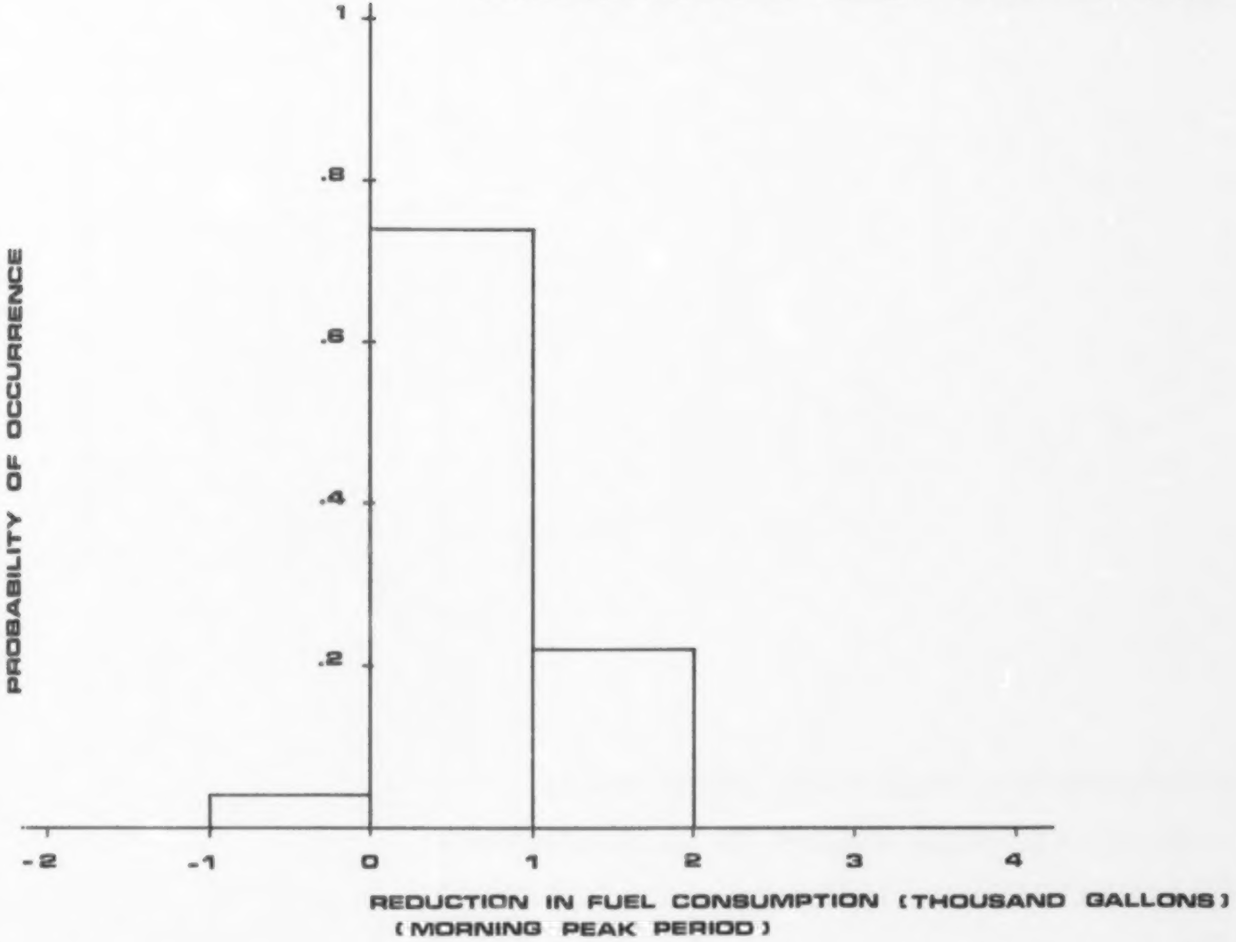
[1] Energy consumption savings are expressed in equivalent gallons of gasoline at the source (one gallon equals approximately 13 KWH of electrical energy).

5.1

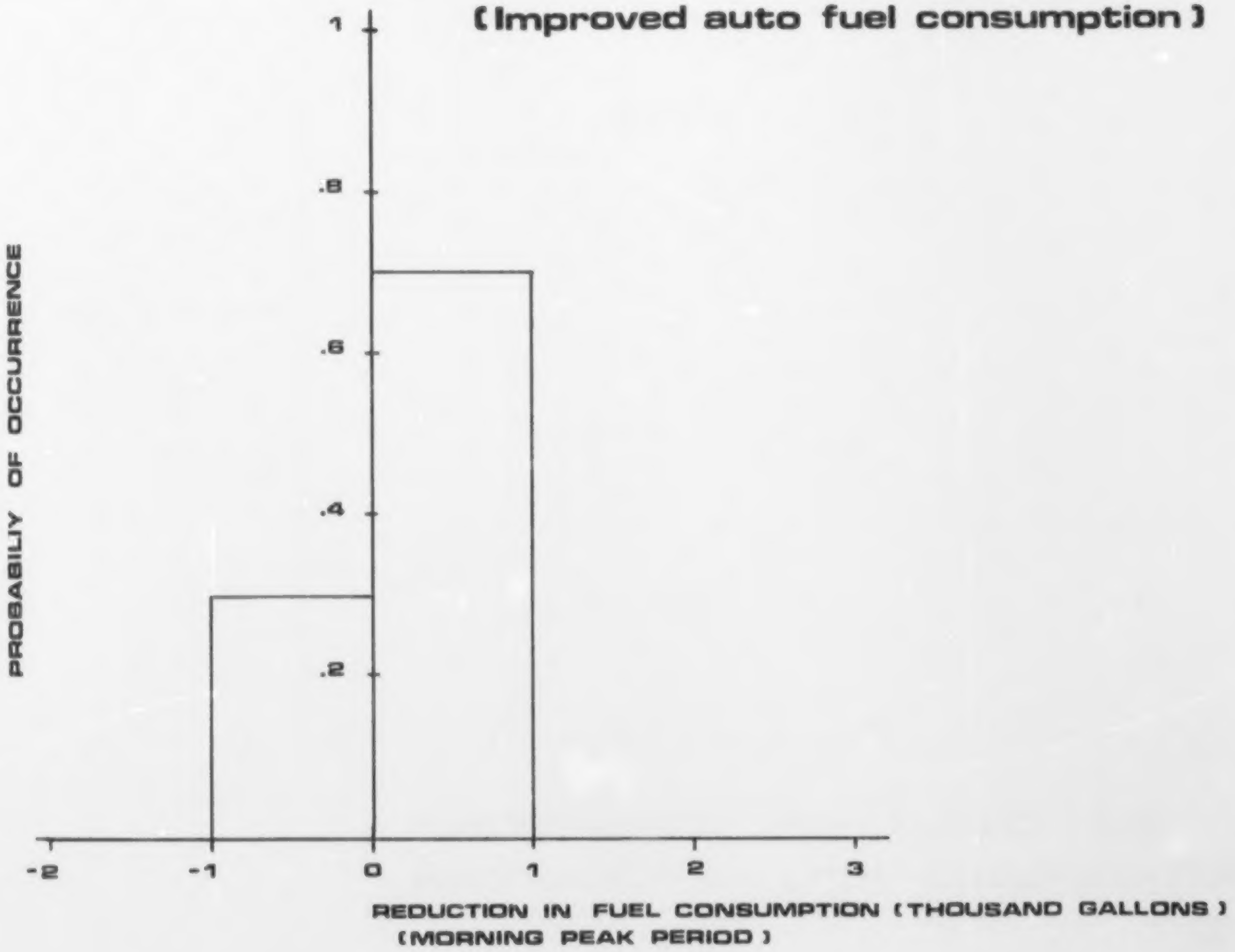
REDUCTION IN FUEL CONSUMPTION
LINDENWOLD HIGH SPEED LINE



5.2

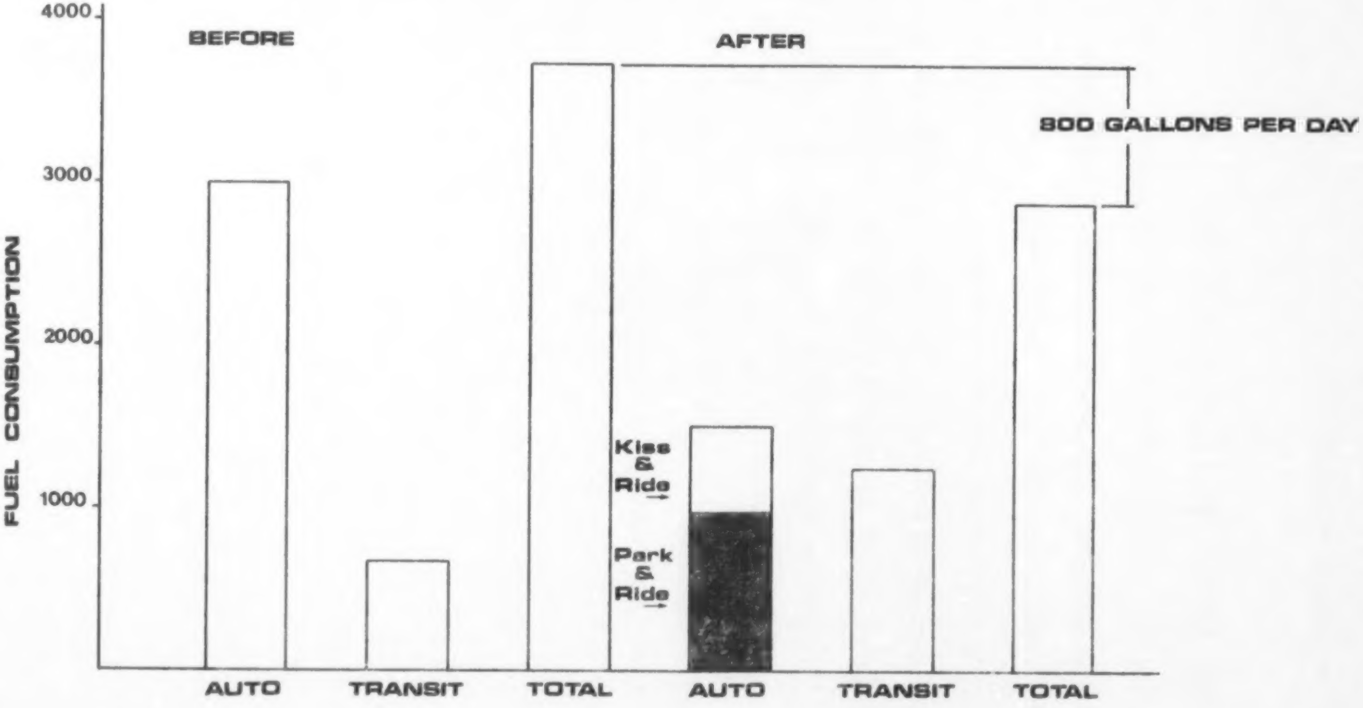
REDUCTION IN FUEL CONSUMPTION LINDENWOLD HIGH SPEED LINE

(Improved auto fuel consumption)



5.3

LINDENWOLD HIGH SPEED LINE BEFORE AND AFTER PEAK PERIOD ENERGY CONSUMPTION



emissions reduced by an estimated 100 kg due to Lindenwold rail transit service. Figure 5.4 shows the probability distribution function determined for CO emissions reduction.

5.4 RAIL TRANSIT AIR POLLUTANT EMISSIONS

Electric vehicles have no direct emissions. Their contribution to air pollution stems from additional loads placed upon the power plants serving the system. Furthermore, power plants do not contribute to the CO or HC problem in significant amounts. However, power plants may be a major source of particulates (TSP), and sulfur and nitrogen compound pollutants.

Using typical conversions and emission factors published by the Environmental Protection Agency, Table 5.8 summarizes the potential contribution of total transit system operations energy for BART and the Lindenwold line on the level of estimated 1975 regional TSP and SO_2 pollutant emissions. In each case, the impact of transit energy utilization is negligible.

5.4

REDUCTION IN CO EMISSIONS
LINDENWOLD HIGH SPEED LINE

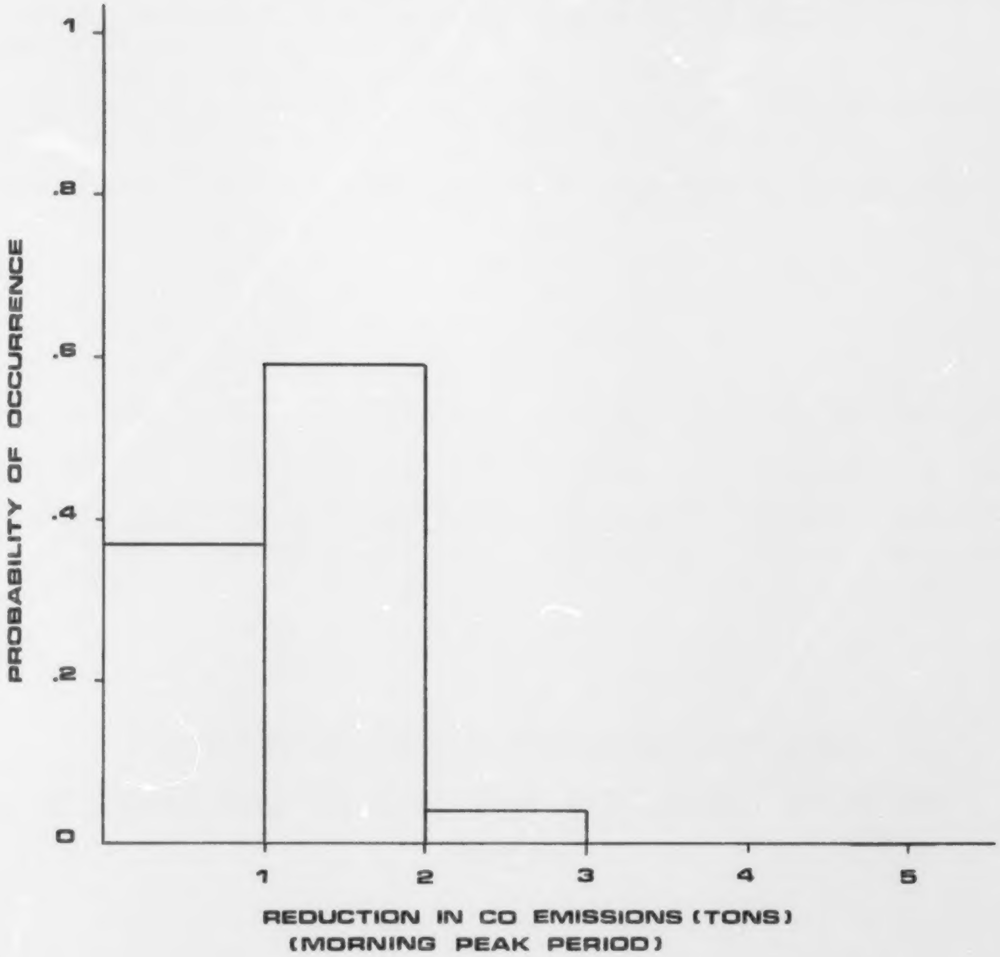


TABLE 5.8

ESTIMATED 1975 CONTRIBUTION OF RAIL TRANSIT OPERATIONS TO ANNUAL REGIONAL AIR POLLUTANT EMISSIONS

	Annual Energy Use (million KWH)	Annual Transit	TSP Emissions Region (a)	(Tons/Year) Percent	Annual Transit	SO_2 Emissions Region (a)	(Tons/Year) Percent
BART	283 (b)	51 (c)	73,415	0.07	317 (c)	89,293	0.36
Lindenwold	38 (d)	110 (e)	1,049,890	0.01	357 (e)	862,913	0.04

Notes:
(a) Estimates by Environmental Protection Agency, 1972 National Emissions Report, June, 1974.
(b) Estimates by Healy, op. cit. for full system operations.
(c) Assumes 1970 electric energy sources distribution for State of California in Healy, "Energy Use of Public Transit Systems", August, 1974.
(d) Estimates by Boyce and Noyelle, op. cit.
(e) Assumes national average electric energy sources distribution in U. S. Department of Transportation, Characteristics of Urban Transportation Systems, May, 1974.

APPENDIX A

METHODOLOGY DESCRIPTION AND INPUT DATA

Three computer models were developed in the course of this study to estimate the impact on total energy consumption and selected air pollutant emissions of transit alternatives:

- Bus service improvements such as increased bus miles of operation, fare reductions, and demand actuated service;
- Corridor service in which buses circulate through neighborhoods collecting passengers, run express on a reserved facility, and then distribute passengers in a city's central business district; and
- Corridor transit service in which the line haul trip is via modern rapid rail to and from the CBD with passenger access by bus, auto, and walking.

A description of the model methodology follows including review of the data used for each of the eight case studies of new/improved transit services.

INPUT DATA

All three models were set up in such a way that they would accept input data in either of two forms:

- Fixed value in cases where the available information was such that no uncertainty existed as to the actual number to be used in the mode. This was the case, for example, for before and after annual bus miles of operation for the Atlanta areawide bus service improvements case study. This data was readily available from routine system reports.

- Random value in cases where the actual value for a case study variable was not known with certainty. This was used, for example, for automobile gas consumption and air pollutant emission rates to reflect fleet characteristics.

Where no direct survey or other data was available, random values were generated from a distribution function defined by probable upper and lower bounds, and by the expected modal value. The upper and lower bound and modal values were obtained using available data from studies for other areas having similar characteristics and from other secondary sources. For example, former auto trip lengths for new transit users, when not available, were obtained by using empirical relationships between trip length and metropolitan population from research studies[1]. The probability distribution would be established by using this point estimate as the modal value with a given percentage then subtracted and added to obtain lower and upper bound values of the distribution.

The lower bound, modal, and upper bound values served to define an approximate beta probability distribution function, from which the values used in each model interaction were sampled[2]. Figure A.1 illustrates a typical probability distribution function defined in this manner. The values of X_1, X_M and X_2 are the lower bound, modal, and upper bound values

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[1] Alan M. Voorhees & Associates. "Factors and Trends in Trip Lengths," National Cooperative Highway Research Program Report No. 48. 1968.

[2] Pei, R. Y. and I. F. Kan. "A decision Aid to Transportation Planners." Paper presented at the 41st meeting of ORSA, New Orleans.

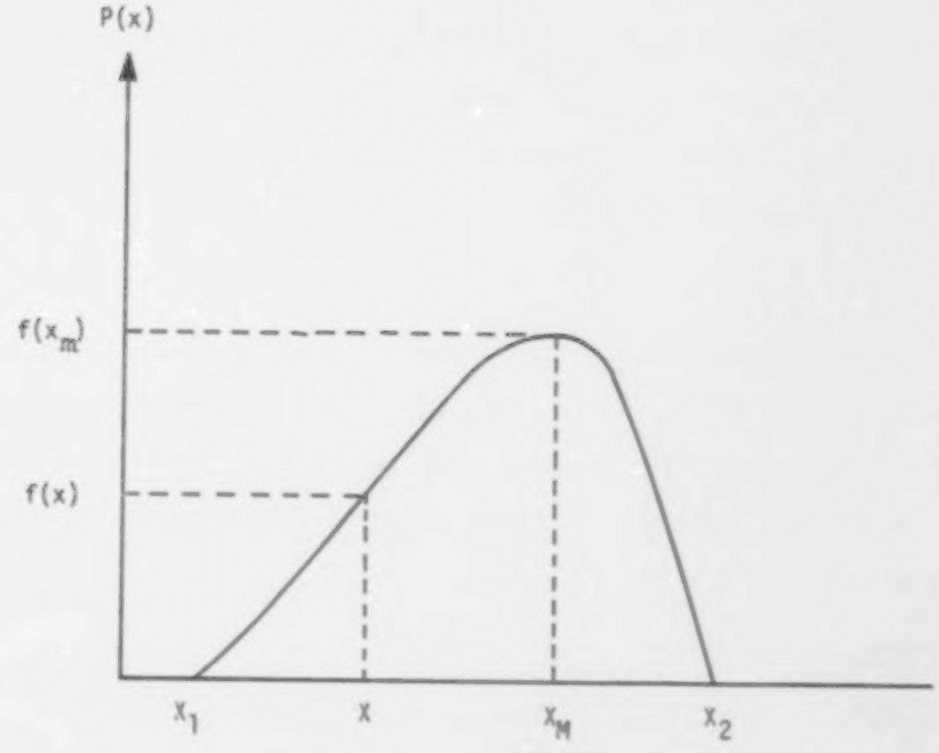

FIGURE A.1
TYPICAL BETA DISTRIBUTION

respectively, of variable x. For any value of x, there is an associated probability of occurrence P(x). All values in the interval are possible but those near the modal value have largest probability, whereas those further from the mode have smaller probabilities of occurrence. Note that the distribution is not necessarily symmetrical and may be skewed as required.

Once the fixed input variables had been determined, they entered all calculations as a single value. The random variables however, would take a different value for each iteration, but always according the established probability distribution function. Iterations results were stored to develop probability functions for output variables. All models were run for two hundred iterations for each case study.

OUTPUT DATA

As a result of the uncertainties associated with the random variables used as input, each iteration would give a different result for the savings in fuel consumption, and the change in total CO and HC emissions. At the end of the iterative process, the stored results would be used to determine output variable distributions.

AREAWIDE BUS SERVICE MODEL

The areawide model estimates the impact of improvements in regional bus service such as expanded annual busmiles, fare changes, and new demand actuated service. It operates in several steps as follows:

(1) Define the lower bound modal and upper bound values of input random variable, namely:

- percentage of previous auto drivers
- auto trip length
- unit auto fuel consumption
- unit auto pollutants emission
- unit bus fuel consumption
- unit bus pollutant emission

(2) Read the breakdown of former auto trips into suburban, corridor, and urban, as percentage of total trip length.

(3) Read the transit ridership and the busmiles of travel for the "before" and "after" conditions.

(4) Read the average trip length of diverted autos. If unknown, use city population to obtain this value as:

$$ATL = 0.46\ P^{(0.19)} \qquad , \text{ and}$$

then establish the range of trip lengths as 80 percent and 120 percent of ATL for the lower and upper bound values, respectively.

(5) Obtain the change in transit ridership and in bus miles of travel.

(6) Estimate effect on ridership due to changes in fare (if any).

(7) Start iterative process for a total of 200 iterations:

- sample all beta distributions to obtain one value for each random variable
- estimate auto VMT reduction
- estimate cold start effect
- estimate fuel savings and reductions in pollutants
- store results, and start a new iteration.

(8) At the end of the iterations, determine the mean and probability distribution of iteration results.

(9) Print the results.

The areawide model was applied to five case studies--Atlanta, Washington, D. C., San Diego (two cases), and Orange County. Tables A.1 through A.5 show the values used in each case study to define the beta distribution of each input variable. Figure A.2 shows an example of the output results for the reduction of CO emissions in the Atlanta case study.

For the San Diego case studies, parametric analysis of diverted auto trip lengths was carried out. Fixed values for this variable of 2.5, 5.0 and 7.5 miles per former auto trip were assumed. Tables A.6 and A.7 list data values used in these parametric studies.

CORRIDOR BUSWAY MODEL

The Busway model assumes a corridor bus system operating with residential passenger collection, express line haul by bus on separate right-of-way, and passenger transfer and distribution in the central business district of the city. It has the following general steps:

(1) Define the low, modal and high values for each of the following random variables:

- unit auto fuel consumption
- unit bus fuel consumption (local service)
- unit bus fuel consumption (on busway)
- unit auto pollutant rates for suburban, highway and urban driving cycles

TABLE A.1

VALUES USED IN AREAWIDE COMPUTER MODEL
ATLANTA, GA.

Variable	Before	After			
	Fixed	Fixed	Random Value		
			Low	Mode	High
VMT Buses ($x10^3$ miles) per year	19,000	23,000			
Transit Ridership (weekdays)	185,090	236,880			
Diversion Rate (%)			20	42	75
Trip Length (Miles)			5.6	6.9	8.3
CO Emission Rate Autos (gr/mi)			47.0	75.0	103.0
CO Emission Rate Buses (gr/mi)			10.9	20.4	32.5
Fuel Consumption Rate Autos (gal/mi)			0.056	0.079	0.081
Fuel Consumption Rate Buses (gal/mi)			0.14	0.23	0.32

TABLE A.2

VALUES USED IN AREAWIDE COMPUTER MODEL
WASHINGTON, D.C.

Variable	Before	After			
	Fixed	Fixed	Random Value		
			Low	Mode	High
VMT Buses ($x10^3$ miles) per year	46,875	54,495			
Transit Ridership (weekdays)	433,100	455,800			
Diversion Rate (%)			20	42	75
Trip Length (Miles)			6.3	7.8	9.4
CO Emission Rate Autos (gr/mi)			47.0	75.0	103.0
CO Emission Rate Buses (gr/mi)			10.9	20.4	32.5
Fuel Consumption Rate Autos (gal/mi)			0.056	0.079	0.081
Fuel Consumption Rate Buses (gal/mi)			0.14	0.23	0.32

TABLE A.3

VALUES USED IN AREAWIDE COMPUTER MODEL
SAN DIEGO FARE REDUCTIONS

Variable	Before	After			
	Fixed	Fixed	Random Value		
			Low	Mode	High
VMT Buses ($x10^3$ miles) per year	8,100	10,444			
Transit Ridership (weekdays)	51,250	82,300			
Diversion Rate (%)			20	42	75
Trip Length (Miles)			5.7	7.1	7.8
CO Emission Rate Autos (gr/mi)			47.0	75.0	103.0
CO Emission Rate Buses (gr/mi)			10.9	20.4	32.5
Fuel Consumption Rate Autos (gal/mi)			0.056	0.079	0.081
Fuel Consumption Rate Buses (gal/mi)			0.14	0.23	0.32

TABLE A.4

VALUES USED IN AREAWIDE COMPUTER MODEL
SAN DIEGO ACTION PLAN

Variable	Before	After			
	Fixed	Fixed	Random Value		
			Low	Mode	High
VMT Buses (x10^3 miles) per year	10,444	17,171			
Transit Ridership (weekdays)	82,300	103,600			
Diversion Rate (%)			20	42	75
Trip Length (Miles)			6.4	8.0	8.8
CO Emission Rate Autos (gr/mi)			47.0	75.0	103.0
CO Emission Rate Buses (gr/mi)			10.9	20.4	32.5
Fuel Consumption Rate Autos (gal/mi)			0.056	0.079	0.081
Fuel Consumption Rate Buses (gal/mi)			0.14	0.23	0.32

TABLE A.5

VALUES USED IN AREAWIDE COMPUTER MODEL
ORANGE COUNTY

Variable	Before	After			
	Fixed	Fixed	Random Value		
			Low	Mode	High
VMT Buses ($\times 10^3$ miles) per year	0	6,288			
Transit Ridership (weekdays)	0	24,000			
Diversion Rate (%)		25 50 75			
Trip Length (Miles)			2.0 4.0 6.0	2.5 5.0 7.5	2.75 5.50 8.25
CO Emission Rate Autos (gr/mi)			47.0	75.0	103.0
CO Emission Rate Buses (gr/mi)			10.9	20.4	32.5
Fuel Consumption Rate Autos (gal/mi)			0.056	0.079	0.081
Fuel Consumption Rate Buses (gal/mi)			0.14	0.23	0.32

A.2

CO EMISSIONS REDUCTION
ATLANTA, GA.

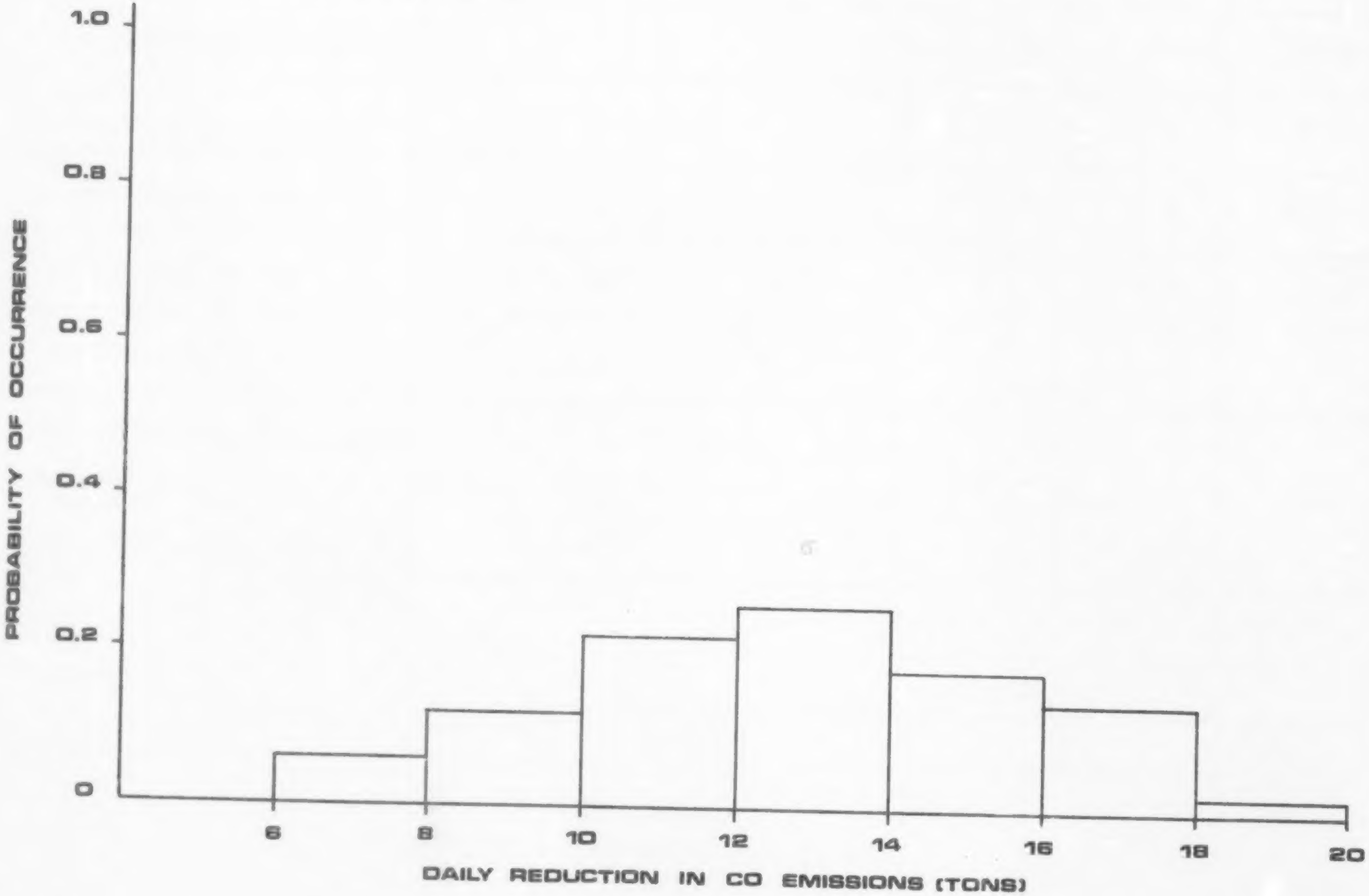

TABLE A.6

VALUES USED IN AREAWIDE COMPUTER MODEL
SAN DIEGO FARE REDUCTION TRIP LENGTH PARAMETRIC ANALYSIS

Variable	Before	After			
	Fixed	Fixed	Random Value		
			Low	Mode	High
VMT Buses (x10^3 miles) per year	8,100	10,444			
Transit Ridership (weekdays)	51,250	82,300			
Diversion Rate (%)			20	42	75
Trip Length (Miles)		2.5 5.0 7.5			
CO Emission Rate Autos (gr/mi)			47.0	75.0	103.0
CO Emission Rate Buses (gr/mi)			10.9	20.4	32.5
Fuel Consumption Rate Autos (gal/mi)			0.056	0.079	0.081
Fuel Consumption Rate Buses (gal/mi)			0.14	0.23	0.32

TABLE A.7

VALUES USED IN AREAWIDE COMPUTER MODEL
SAN DIEGO ACTION PLAN TRIP LENGTH PARAMETRIC ANALYSIS

Variable	Before	After			
	Fixed	Fixed	Random Value		
			Low	Mode	High
VMT Buses (x10^3 miles) per year	10,444	17,171			
Transit Ridership (weekdays)	82,300	103,600			
Diversion Rate (%)			20	42	75
Trip Length (Miles)		2.5 5.0 7.5			
CO Emission Rate Autos (gr/mi)			47.0	75.0	103.0
CO Emission Rate Buses (gr/mi)			10.9	20.4	32.5
Fuel Consumption Rate Autos (gal/mi)			0.056	0.079	0.081
Fuel Consumption Rate Buses (gal/mi)			0.14	0.23	0.32

- unit auto pollutant emission rates for trips done to park-and-ride and kiss-and-ride sites
- bus pollutant emission rates
- bus load factor (residential collection)
- bus load factors (line haul)
- bus load factors in the busway during off-peak periods
- average trip length for park-and-ride and kiss-and-ride access trips.

(2) Read input data:

- distribution of trips (percent of total trip in suburbs, highway and downtown)
- percent of new riders using park-and-ride and kiss-and-ride modes
- before and after ridership, number of routes and maximum and minimum bus service frequencies.

(3) Estimate diverted passengers, and cold start effects.

(4) Start iterative process:

- generate a random value for each random variable from its beta distribution
- estimate bus-miles of travel before and after implementation of the busway
- estimate auto VMT reduced by trips diverted to bus
- calculate new auto VMT due to park-and-ride and kiss-and-ride.

  - estimate total fuel savings and reduction in emission of pollutants for this iteration, store results
  - repeat the process for 200 iterations.

(5) Determine the mean values and probability distributions of output.

(6) Print results.

The Busway model was applied to two case studies--the Shirley Busway in the Washington, D. C. metropolitan area, and the San Bernardino Busway in the Los Angeles area. Tables A.8 and A.9 list data used for each case study.

CORRIDOR RAIL TRANSIT MODEL

The CORAIL computer model assumes corridor transit service in which the line haul part of the trip is made via modern rapid rail transit into the central business district of the city. Passenger access to the system may be by feeder bus, auto, or walking according to user-supplied data. The model is very similar in assumptions to the Busway model. CORAIL incorporates, in addition to the variables used by Busway, the bus miles of travel generated by the feeder bus service. The gas consumption and pollution emission of this service is also taken into consideration in estimating system outputs. CORAIL was applied to the Lindenwold Rapid Rail case study, using the variables and values shown in Table A.10.

TABLE A.8
VALUES USED IN BUSWAY COMPUTER MODEL
SHIRLEY BUSWAY

		Before				After			
		Fixed	Random Value			Fixed	Random Value		
			Low	Mode	High		Low	Mode	High
Passengers (peak)		8,050				23,000			
Bus Load Factors			30	35	50		40	47	55
Diversion Rate						40%			
P&R						24%			
K&R						9%			
P&R Travel Distance							1.0	2.0	4.0
Auto Fuel Consumption (gal/mi)			0.056	0.079	0.081		0.056	0.079	0.081
Bus Fuel Consumption			0.14	0.23	0.32		0.14	0.18	0.27
Auto CO Emission (gr/mi)	Suburb		47.0	75.0	103.0				
	Express		27.0	41.0	55.0				
	CBD		47.0	87.0	128.0				
	P&R						47.0	75.0	103.0
Bus CO Emissions			10.9	20.4	32.5		10.9	15.0	32.5
Trip Length			11.2	14.0	18.2				

TABLE A.9

VALUES USED IN BUSWAY COMPUTER MODEL
SAN BERNARDINO BUSWAY

		Before				After			
		Fixed	Random Value			Fixed	Random Value		
			Low	Mode	High		Low	Mode	High
Passengers (peak)		190				9,500			
Bus Load Factors			30	35	50		40	47	55
Diversion Rate						77%			
P&R						55%			
K&R						17%			
P&R Travel Distance							1.0	3.0	5.0
Auto Fuel Consumption (gal/mi)			0.056	0.079	0.081		0.056	0.079	0.081
Bus Fuel Consumption			0.14	0.23	0.32		0.14	0.18	0.27
Auto CO Emission (gr/mi)	Suburb		47.0	75.0	103.0				
	Express		27.0	41.0	55.0				
	CBD		47.0	87.0	128.0				
	P&R						47.0	75.0	103.0
Bus CO Emissions			10.9	20.4	32.5		10.9	15.0	32.5
Trip Length			11.2	14.0	18.2				

TABLE A.10

VALUES USED IN CORAIL COMPUTER MODEL

LINDENWOLD RAPID RAIL

		Before				After			
		Fixed	Random Value			Fixed	Random Value		
			Low	Mode	High		Low	Mode	High
Passengers (peak)		6,900				8,000			
Bus Load Factors			30	35	55		30	35	55
Diversion Rate						40%			
P&R						59%			
K&R						20%			
P&R Travel Distance							1.0	3.0	5.0
Auto Fuel Consumption (gal/mi)			0.056	0.079	0.081		0.056	0.079	0.081
Bus Fuel Consumption			0.14	0.23	0.32		0.14	0.23	0.32
Auto CO Emission (gr/mi)	Suburb								
	Express						47.0	75.0	103.0
	CBD								
	P&R						47.0	75.0	103.0
Bus CO Emissions			10.9	20.4	32.5		10.9	20.4	32.5
Trip Length			7.5	9.3	13.0		11.2	14.0	15.4
Rail Load Factors							60	75	85
Rail Fuel Consumption							0.28	0.41	0.45
Rail CO Emissions							0.0	0.0	0.0

APPENDIX B

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